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Diurnal variation of visibility of objects at different altitudes and in different directions during the cold season at Poona and its neighbourhood.

BY

C. S. Karve.

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DIURNAL VARIATION OF VISIBILITY OF OBJECTS AT DIFFERENT ALTITUDES AND IN DIFFERENT DIRECTIONS DURING THE COLD SEASON AT POONA AND ITS NEIGHBOURHOOD.

BY

C. S. KARVE.

(Received on 2nd December 1940.)

Abstract.—There is a marked diurnal variation in the visibility of objects in and near Poona during the cold season. The visibility is usually fair at sunrise but deteriorates rapidly, becoming very poor generally at some hour between 8 and 10 hrs. (most frequently between 8 and 9 hrs) and rapidly clearing before 11 hrs. As observed from the tower of the Poona Meteorological Office, the visibility minimum is reached earliest in a direction towards the north-east and latest towards the south-west. This is mainly due to the prevailing north-easterly to south-easterly wind carrying the haze in that direction. Comparing similar objects at nearly the same distance and direction, the deterioration of visibility takes place earlier for lower objects than for higher ones. The improvement of visibility also begins slightly earlier for lower objects, but the change is rapid and the clearing takes place practically simultaneously for lower and higher objects. At the time of lifting fog (a rare phenomenon at Poona) higher objects become visible earlier than the lower ones.

The diurnal variation of visibility of objects in winter on days of clear undisturbed weather as seen from Fort Purandhar (4,560 ft. above sea level) is appreciably different from that observed from Poona (1,850 ft above sea level). The minimum of visibility which takes place in the forenoon occurs two to three hours later at Fort Purandhar, and the time of clearing of haze is also correspondingly delayed to some hour between 12 and 14 hrs. The coefficient of eddy diffusion calculated from the lag in the time of maximum haziness or clearing of haziness comes out to be $8{\cdot}9\times10^4$ cm.^{2}/sec. which is in approximate agreement with the value deduced by Barkat Ali from the variation of wind with height at Agra for the period February to April.

Introduction.

In a paper on "Fog and haze at Poona during the cold season" published as a Scientific Note of the India Meteorological Department, Ramdas and Atmanathan[1] have discussed in a general way the almost daily occurrence of haze over Poona during the winter season and its changes during the early hours of the day. They have pointed out that the upper boundary of the haze layer which is sharp at night and in the early morning, becomes more and more diffuse as the ground gets heated by sunshine and thermal convection sets in, and by about 9 hrs., the fog or haze generally disappears from the surface layers. Also in a paper on "Solar Radiation at Poona" S. S. Kohli[2] has commented on the large effect of the raising of haze on the intensity of solar and sky radiation received on a horizontal surface at about 9 hrs. during the winter months.

The haze in the atmosphere over Poona and its neighbourhood in these months is mainly due to the raising of surface dust and smoke during the hot hours of the day by thermal convection and turbulence and their settling at night. Large lapse-rates of 8 to 10°C per kilometer prevail during afternoon hours upto $1\frac{1}{2}$—2 kilometers.

In addition to a more or less permanent dust boundary at about this height, there is yet another boundary very close to the surface of the earth marking the top of the surface dust and smoke. Within a couple of hours after sunset, the boundary settles down with a sharp upper limit and this condition persists throughout the night with occasional disturbances due to katabatic winds.

In the morning hours, as the sun rises up and the ground gradually gets heated, the whole mass of this night haze is lifted by the convection currents. A result of this upward movement of haze is the gradual deterioration of atmospheric visibility of objects at different altitudes. The visibility of objects at increasing heights gets impaired in succession as the haze rises. However, the movement is not confined to the vertical direction alone; there is also a lateral movement of the haze due to winds. As a consequence, the atmospheric visibility of objects in different directions and altitudes gets deteriorated in a more or less systematic manner depending on the weather condition.

In a thesis on the diurnal variation of visibility in the cold season at Poona and Bombay, the author has discussed the variation of atmospheric visibility due to haze in different directions.

As the vertical movement of the haze is also important for an understanding of the phenomenon, a new series of half-hourly observations on objects at different altitudes, but at nearly the same distance were taken during the cold season of 1939-40. The observations were carried out from the tower of the India Meteorological Office, 120 feet above the ground, with the help of visibility meter prepared locally by the author according to the suggestions of Dr. K. R. Ramanathan. The visibility meter is made on the same general principles as the Bennett instrument. but instead of using a number of graded discs, a battery of discs of the same uniform

character is employed. For comparison, the equivalent disc numbers of Wigand and Bennett meters corresponding to the disc numbers of the Indian instrument are given in *Table I*.

TABLE I.

Corresponding readings of Wigand, Bennett, and the locally made visibility meters under day time conditions.

Indian Visibility Meter	Wigand Meter.	Bennett Meter.
1	1	1
2	2·5	2·5
3	3	4
4	5·5	5
6	8	6, 10*
8	12	14
10	13	16
12	14	19

The observations were commenced in the early hours of the morning and continued till noon by which time the haze gets well mixed up and practically disappears. In part I, the results of these observations on a few selected days are discussed. In part II, the visibility observations made in the winter of 1937 from Poona and Fort Purandhar (at a height of 4,560 ft. above sea level) on four consecutive days of very similar weather are discussed.

PART I.

Place of Observations, Visibility landmarks, etc.

A general idea may be given of the situation of the observatory and the main features of its surroundings. The town of Poona is situated at a distance of about 30 miles to the east of the ridge of the Western Ghats. Its height above sea level is 1,850 ft. and the town is in the midst of a country which is rugged on its western side becoming more and more level towards the east. The Observatory is situated between two small rivers, the Mutha and the Mula, which join together at a distance of about three-fourths of a mile to the east of the Observatory. The Mutha flows from the south-west from Khadakwasala lake and the Mula from a northerly direction when it approaches Poona and from a north-westerly direction farther up. There are thus two river valleys converging towards the east of the Observatory, the more important of the two valleys being the one towards the south-west. This valley and the surrounding hills have a large influence on the local winds of Poona and also on the diurnal variation of visibility at the place. The city of Poona and its suburbs are situated to the east and south-east of the Observatory.

Throughout the period November to February, Poona is in an anticyclonic area. In the early part of this period, when the north-east monsoon is still active in the south

*The anomalous readings given by the Bennett's visibility meter have been investigated and the esults will be discussed in another paper.

of the Indian Peninsula, south-easterly winds are common, but in January and February, with the retreat of the north-east monsoon to the south of Indian area, the south-easterly winds gradually change to north-easterlies. At the surface, calms are frequent at night and in the early morning. There is a diurnal rotation of wind, the direction being generally south-easterly to north-easterly during the day hours (occasionally becoming north-westerly in the late afternoon hours owing to the incursion of the sea breeze) and south-westerly or north-westerly during the night hours. The westerly winds are generally very shallow and are "katabatic winds" flowing down river valleys. It is during the times of transition between katabatic winds and gradient winds when the surface wind is very weak, that the maximum deterioration of visibility occurs at Poona.

Observations were taken on a large number of days. The results obtained on a few typical days are discussed below. A table containing the information about the azimuth and the distance of different objects is given below.

TABLE II.

Visibility landmarks at Poona and their azimuths and distances from the Meteorological Office.

Object. No.	Azimuth.	Distance in km.	Height above the place of observation in meters.	Description.
1	19°	11·2	30	A low hill.
2	20°		105	Saddle between two hills.
3	24°		180	Top of a hill.
4	59°	3·8	30	Top of a small hill.
5	61°		—30	Lower portion of the same hill.
6	134°	19·2	330	Saddle between two peaks of a hill.
7	136°		420	Peak of the same hill.
8	174°	14·4	330	Saddle between two peaks of a hill.
9	176°		480	Peak of the same hill.
10	207°	22·4	630	One corner of the flat top of Sinhagad hill.
11	211°		480	Saddle just below it.

Eleven different objects were chosen, all of them being hills against a sky-background.

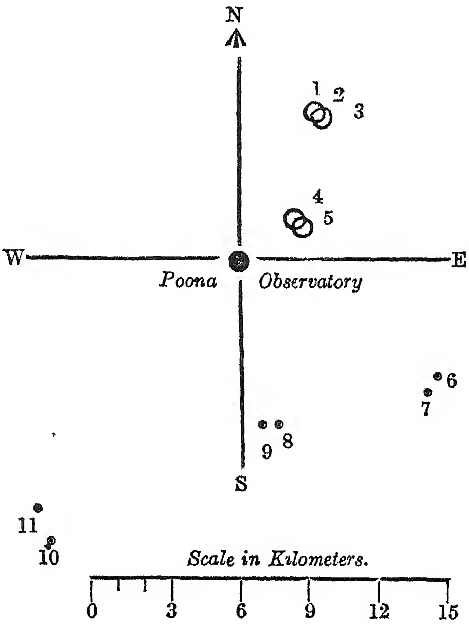

FIG. 1—POSITIONS OF VISIBILITY LANDMARKS AT POONA.

From the chart (*Fig. 1*) it will be seen that objects were selected in different directions, but in order to study the effect of altitude, pairs of objects were chosen in nearly the same azimuth and the same distance.

The observations were made with the visibility meter at intervals of nearly fifteen minutes. The values of the readings of the visibility meter against the time of the day are plotted in the *Figures 2 to 5*. A circle indicates the reading for the object at the higher altitude while a cross shows the reading for the one at the lower altitude. In the north-north-easterly direction alone, three objects at three different heights were chosen for observation. Along with the curve of variation of visibility, the wind directions and speeds on the Beaufort scale at half-hourly intervals are also given.

Results of Observations of four selected days.

28th November, 1939. (*Fig. 2*).—On this day there was a south-westerly breeze for a number of hours preceding daybreak and in the early morning. At about 7-30 a.m. the breeze died down and there was almost calm up to 9-45 a.m. The movement of the haze after sunrise was mainly due to the convection currents set up by solar heating, and was vertical with little or no lateral movement. From 9-45 a.m. a weak northerly to easterly wind sprang up which became more and more gusty. With the development of this wind, the haze was rapidly wafted away.

Up to 9 a.m. the vertical movement of air was mainly responsible for the changes of visibility and therefore the visibility of objects at lower altitude deteriorated more rapidly than that of objects at higher altitudes. The objects in the north-easterly quadrant were obscured by haze (from a factory in the north) earlier in the day, while objects towards south and south-west being away from the city and suburbs, their obscuration occurred after 9-30 a.m. when the north to easterly wind caused the movement of the city haze towards those directions.

It will be observed from the curves that in every direction the visibility of the objects at lower altitudes became worse earlier than those of the objects at the higher altitude in the same azimuth. Also in every case the improvement of visibility of both the higher and lower objects took place practically simultaneously.

Notes on Visibility on 28th November 1939.

0730 hrs.—Hills towards the south, south-east and south-west are very clearly visible, while hills towards the north, north-east as well as the part of the city in that direction are seen completely enshrouded in the early morning haze.

0800 hrs.—Hills to the south, south-east and south-west getting gradually poorer in visibility and the visibility of hills towards the north and north-east is very bad. The top of the haze boundary is gradually lifting in all directions.

0900 hrs.—Visibility of objects towards the north-north-east is rapidly improving while visibility in the south and south-east directions is getting worse.

0930 hrs.—Objects towards the city of Poona and Kirkee (north and north-east) becoming clearly visible. Haze on the eastern part of the city is gradually lifted up. Hills towards the south-east, south and south-west are now getting enveloped in rising haze.

1000 hrs.—Gradual movement of city haze towards the south and south-west is clearly marked and the visibility in that direction is getting worse. Haze boundary has gone high up in the sky.

1100 hrs.—All directions are clear of haze.

2nd December, 1939. (*Fig. 3*).—The easterly and south-easterly wind between 8 p.m. and midnight on the 1st had drifted the haze from the city area towards the west and south-west. From midnight up to 8 a. m. on the 2nd, there was calm and so the haze brought to west and south-west on the previous night had settled in the early morning hours and gathered near the ground. As the heating of the ground commenced in the morning the vertical movement of this haze caused an unusual deterioration of visibility in these directions, while the visibility in the north was much better than usual and improved rapidly as the convection currents set in accompanied by north-easterly breeze at 9 a. m.

The north-easterly breeze which commenced at 9 a. m. drifted some of the haze from the city area towards the west and south-west and so the improvement of visibility in these directions was not as rapid as on the 28th November.

The curves on this day clearly show a greater obscuration of the lower objects. This is particularly marked in the case of objects towards the south and south-west where the difference in altitude in each pair of objects is 500-600 ft.

The improvement of visibility of objects at different altitudes in the same direction commences at about the same time.

Notes on visibility on 2nd December, 1939.

0730 hrs.—The day seems to be exceptional. The haze is very thick towards the south, south-east, and south-west directions while towards the north it is thin. The lower hills towards the south-east, south and south-west are gradually getting bad visibility while the top of the hills are not yet affected. The city is completely under the mask of the haze.

0800 hrs.—Haze boundary towards the south-east, south and south-west direction is rising rapidly. The objects at lower levels are almost invisible while those at higher altitudes are gradually getting bad visibility. The upward movement of haze is clearly seen. Waves after waves are seen moving upwards. The north-east side is gradually deteriorating in visibility.

0830 hrs.—The visibility of objects towards the city and Kirkee in the north-east quadrant is rapidly improving while the haze has now come up to the tops of hills towards the south-east, south and south-west directions.

0900 hrs.—Almost all the haze towards the north and north-east is dispersed. The objects towards the south-east, south and south-west are still affected

1000 hrs.—Good visibility in all directions.

15th January, 1940. (*Fig 4*).—On this day, there was a south-westerly breeze from midnight to 8-30 a.m. Between 7 and 8-30 a.m. the wind was very weak and the speed did not exceed 1 mile per hour. However, it increased afterwards and the direction also changed to the north-west between 8-30 and 10 a.m. and then to north-east, gradually veering to the east.

Due to the south-westerly breeze throughout the early morning hours only a small quantity of haze settled in the south and south-west directions and so the visibility of objects towards these directions was not much deteriorated. In the case of objects towards the north, when the lower object at 30 meters had begun to improve in visibility, the object at a height of 105 meters was still getting poorer in visibility. As the obscuration of the object at 105 meters height reached its maximum, the north-westerly breeze sprang up and drifted the haze towards the city so that the still higher object at a height of 180 meters was not affected at all.

The effect of altitudes was marked in the morning deterioration of visibility of all the objects. The improvement began at the same time for the lower as well as the higher level objects in the same direction.

Notes on visibility on 15th January, 1940.

0800 hrs.—Usual strong haze towards the east but fairly good visibility towards the north.

0815 hrs—Perfect calm. Haze boundary being gradually lifted up.

0830 hrs.—Haze being carried towards the south-east and visibility in that direction is getting poor.

0845 hrs—Visibility improved towards the north; north-easterly breeze is delaying the deterioration of visibility towards the south-east.

0900 hrs.—North-easterly to north-north-easterly fresh breeze.

1015 hrs.—Good visibility in all directions except towards the south-south-east.

19th January, 1940. (*Fig. 5*).—This was a very exceptional day. For three or four days previous to it, the skies were heavily clouded and there was rainfall on the 18th. The high humidity of the air caused a very dense fog in all directions on this day.

There was a weak south-westerly breeze throughout the early morning hours which continued upto 10 a.m. with a slight change to westerly or north-westerly between 7 a.m. and 8 a.m. The wind speed did not exceed 2 miles per hour between 7 a.m. and 10-30 a.m.

The fog was so thick and heavy that nothing could be seen even at a distance of 100 yards. The visibility only improved from 9-30 a.m. when the convection currents were strong enough to raise and disperse the heavy fog. The weak south-westerly breeze which re-started at about 9 a.m. improved the visibility in the south and south-west directions earlier than in other directions. From 9-30 a.m. there was a rapid improvement of visibility in all directions. The lateness of the hour of improvement was due to the fact that it commenced only with the mixing of the upper air with the ground air.

The most peculiar phenomenon on this day was the reversal of the usual altitude effect. Except in the case of objects towards the north-north-east, the visibility of the higher objects improved earlier than that of the lower objects in the same direction. It should be remembered that the place of observation was the top of a tower.

Notes on visibility on 19th January, 1940.

0800 hrs.—Very heavy fog in all directions. From the tower of the Observatory nothing can be seen even in the compound of the office. There is a mild south-westerly breeze of about 2 miles per hour.

0900 hrs.—Heavy fog in all directions. However, the condition is steadily improving and now one can see easily the traffic on the road near the office.

0920 hrs.—Much improvement in the situation. Haze and fog boundary has been lifted high in the atmosphere. Nearer hills in the south-west directions are now seen.

0930 hrs.—The appearance is unusual. Haze boundary is seen clearly lying below the hill tops and the higher altitude hills stand out clear while the lower altitude hills are poorly seen. This is particularly marked towards Sinhagad (south-south-west.)

0945 hrs.—Haze boundary near the bases of the hills, instead of rising up by convection is sinking down.

1030 hrs.—Good visibility in all directions.

Observations were taken on many other days, but the general results are similar to those found on one or other of the days discussed above.

PART II.

Diurnal variation of visibility at Poona compared with that at Fort Purandhar.

It has been stated above that the minimum of visibility at Poona for such objects as distant hills during the winter months occurs most frequently between 0800 and 0900 hrs. By 0900 hrs. thermal convection raises up the ground-fog and haze to about half a kilometer above the ground. It may be expected that if observations are taken from a higher level in the atmosphere, horizontal visibility would show marked decrease only some time after the decrease near the surface, because it would take more time to raise the surface dust and haze by eddy diffusion to greater heights in the atmosphere.

In order to examine this, a series of visibility observations were taken by the author from two positions at different heights in the cold season of 1936-1937 and are given here. The observations were taken with the help of a Wigand meter. The two places of observation were Poona and Fort Purandhar 19 miles to the south-south-east of Poona and 4,560 feet above sea level, *i.e.*, 2,710 feet above Poona.

The choice of visibility landmarks at Poona was a little different from those given in the first part. They were only four in number. Their azimuths and distances are given in *Table III* and are also shown in *Fig. 6*.

TABLE III.

Visibility landmarks at Poona.

Object.	Azimuth.	Distance in Km.	Height (above the place of observation in meters).	Description.
1	115°	33 6	275	Top of a hill.
2	68°	18·4	76	Top of Barometer Hill.
3	207°	22·4	610	Corner of flat top of Sinhagad.
4	307°	36 0	458	Top of a hill.

The place of observation at Poona was the tower of the Meteorological Office. The visibility objects chosen at Fort Purandhar are shown in *Fig. 7* and *Table IV*. The place of observation there was the highest peak, Kedareshwar Peak, whose height is 4,560 feet above sea level. The observations at Fort Purandhar and Poona were taken on four successive days, two days of observation at Fort Purandhar coming in between the days of observation at Poona. The days were all clear and very similar as regards the character of the weather.

TABLE IV.

Visibility landmarks at Fort Purandhar.

Object.	Azimuth.	Distance in Km.	Height (below the place of observation in meters).	Description.
3	295°	25·6	—168	Corner of flat top of Sinhagad.
4	310°	50·4	—473	Top of a hill.
5	340°	40·8	—702	Top of a hill.
6	2°	36·0	—702	Top of a hill.
7	35°	16·0	—473	Top of a hill.
8	100°	12·8	—625	Top of a hill.

The results of the observations at Poona on 4th February, 1937 and on 7th February, 1937 are shown in *Figures 8 and 9* respectively. On both days the visibility of objects 1 and 2 (hills to east-south-east and east-north-east of Poona respectively) showed a decrease after sunrise, reached a minimum at 0800 to 0900 hrs. and showed a rapid improvement after 0900 hrs. The objects towards the south-west and north-west did not show much change during the day. The curves of variation of visibility at Purandhar had a family resemblance to those at Poona but the minimum of visibility was reached at about 1100 hrs. and improvement began only after about 1300 hrs. (except in the case of object 4 on the 6th). It seems clear that the minimum of visibility in a horizontal direction is reached about 2 to 3 hours later as seen from Purandhar than as seen from Poona.

Comparing for instance the change of visibility of an object in the south-easterly direction at Poona with that of an object in the opposite direction (north-westerly) at Purandhar, the deterioration of visibility at the former place begins at 0730 hrs. while in the latter place it begins only at 1030 hrs. Using the relation—

$$Z_2^2 - Z_1^2 = 4k\ (t_2 - t_1)$$

where $t_2 - t_1$ is the time required for the haze to rise from a height Z_1 to a height Z_2 and k is the coefficient of eddy diffusion, we can easily make an approximate estimate of k.

Assuming Z_1 to be mean of the heights of the place of observation at Poona and of the visibility landmark to the south-east, both heights being measured above the general level of Poona, $Z_1 = \frac{150+1050}{2}$ ft. $=600$ ft. above Poona level and similarly Z_2, the mean of the heights of Purandhar and of the visibility landmark to its north-west $= \frac{2710+1150}{2} = 1930$ ft. above Poona level and

$$t_2 - t_1 = 2\cdot5 \text{ hrs.} = 2\cdot5 \times 60 \times 60 \text{ sec.}$$
$$k = \frac{(1930^2 - 600^2)}{3600} \times 30\cdot48^2 = 8\cdot9 \times 10^4 \quad \text{cm.}^2\text{/sec.}$$

It has been assumed in the above that the eddy diffusion spread upward from the general ground level at Poona, *i.e.*, 1,850 ft. above sea level.

From the variation of wind with height during the period February to April at Agra between the heights 22 meters and 330 meters above ground, Barkat Ali[3] found k to be $3\cdot9 \times 10^4$ cm.^{2}/sec. at 1000 hrs. and $11\cdot0 \times 10^4$ cm.^{2}/sec. at 1300 hrs. Barkat Ali also determined k on days when a changed wind-direction showed itself in the morning pilot balloon trajectory within the first 1 or 2 km. above ground, using for this purpose the time at which the upper wind direction began to appear in the Dines wind chart. In this manner, Barkat Ali found a mean value of $k = 2\cdot25 \times 10^5$ cm.^{2}/sec. He however points out that a sharp change of wind direction in the first 1 or 2 km. usually occurs in disturbed weather. The agreement in the values obtained by different methods in the two places can be considered satisfactory.

The thanks of the author are due to Dr. K. R. Ramanathan under whose direction the above work was carried out.

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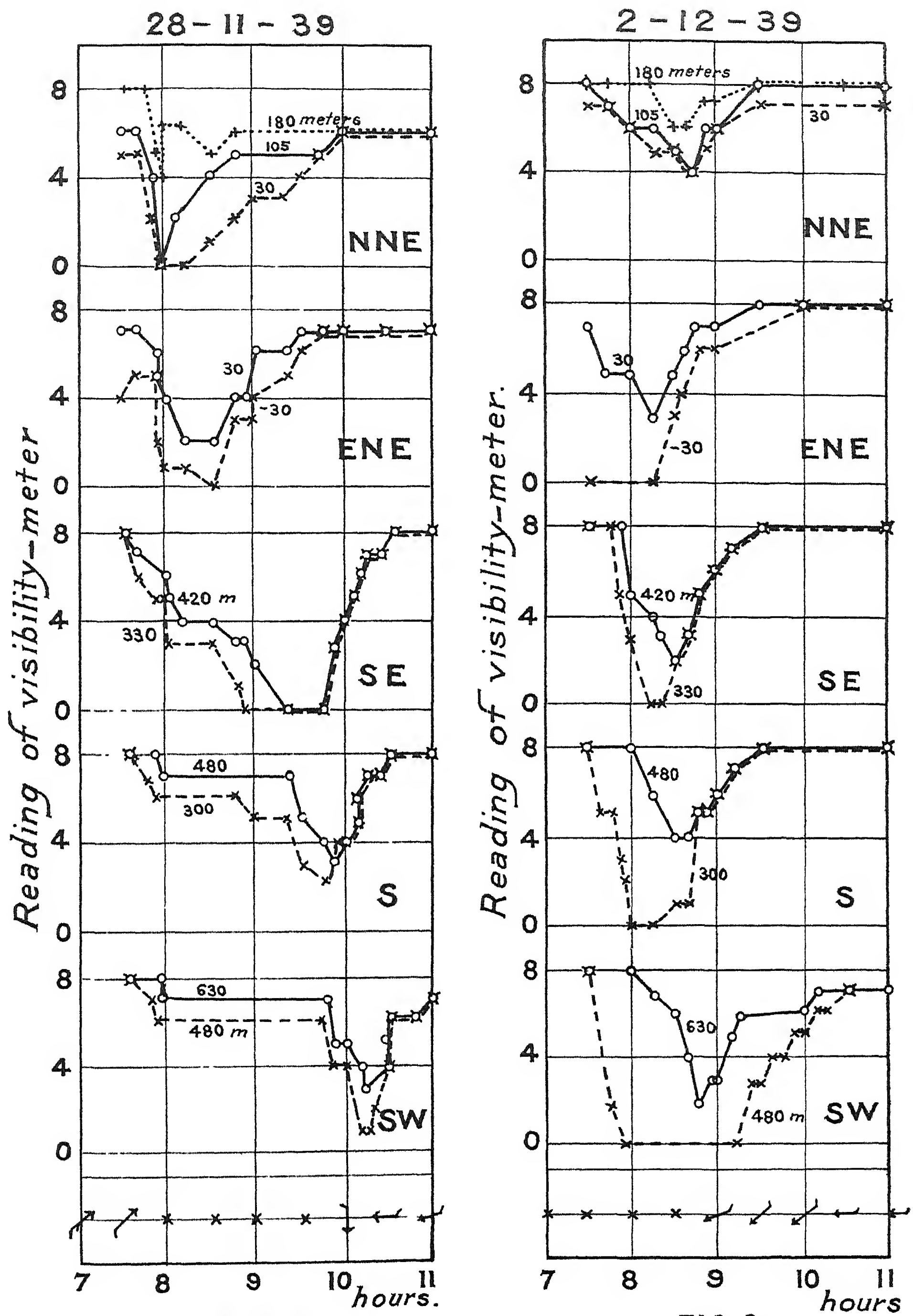

FIG. 2.

FIG. 3.

VARIATION OF VISIBILITY WITH TIME AT POONA

The figures by the side of the curves are the heights of the respective visibility landmarks above the level of the place of observation.

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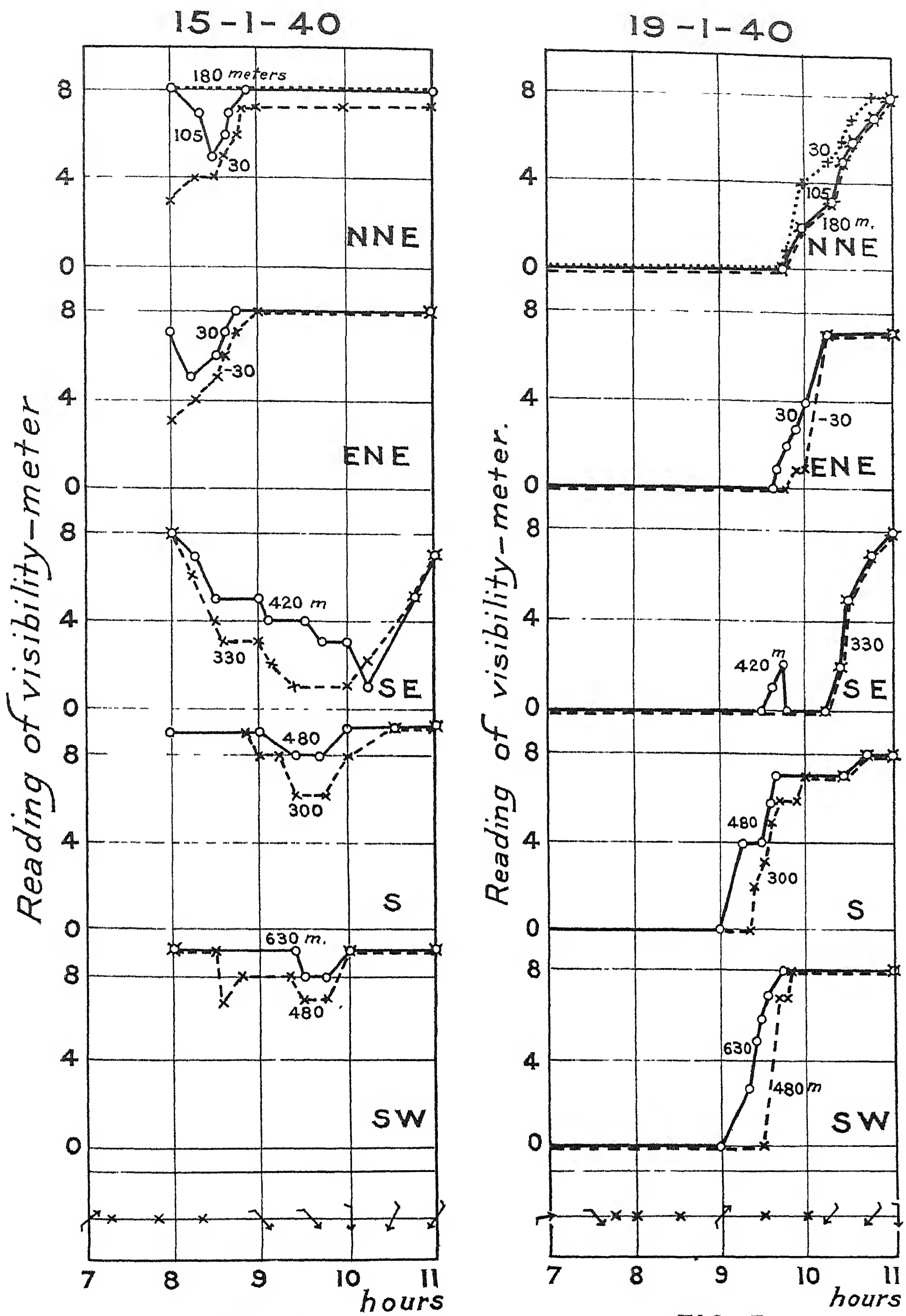


FIG. 4.

FIG. 5.

VARIATION OF VISIBILITY WITH TIME AT POONA

The figures by the side of the curves are the heights of the respective visibility landmarks above the level of the place of observation.

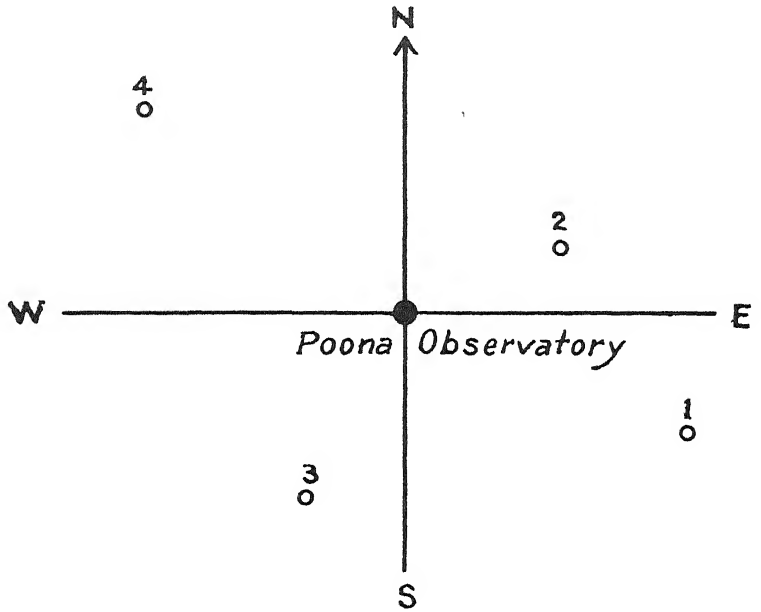


FIG. 6. POSITIONS OF VISIBILITY LANDMARKS AT POONA FOR COMPARATIVE OBSERVATIONS WITH PURANDHAR.

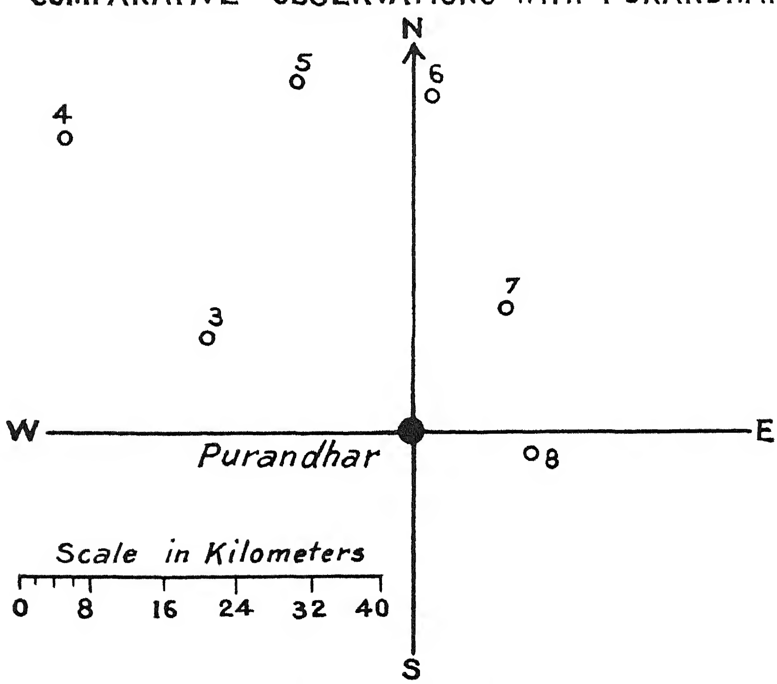
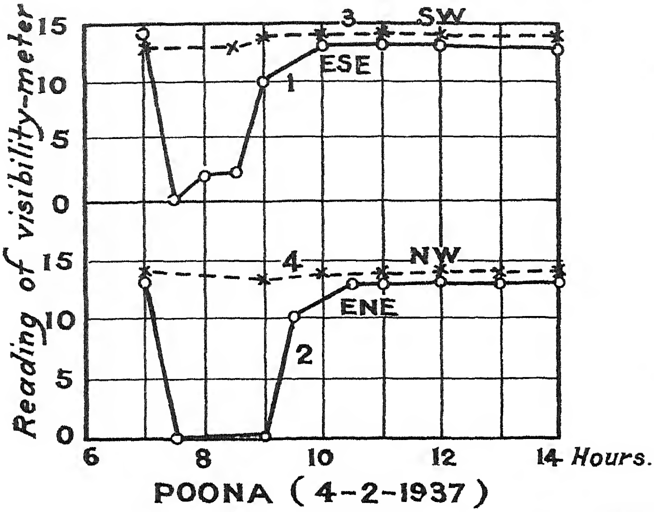
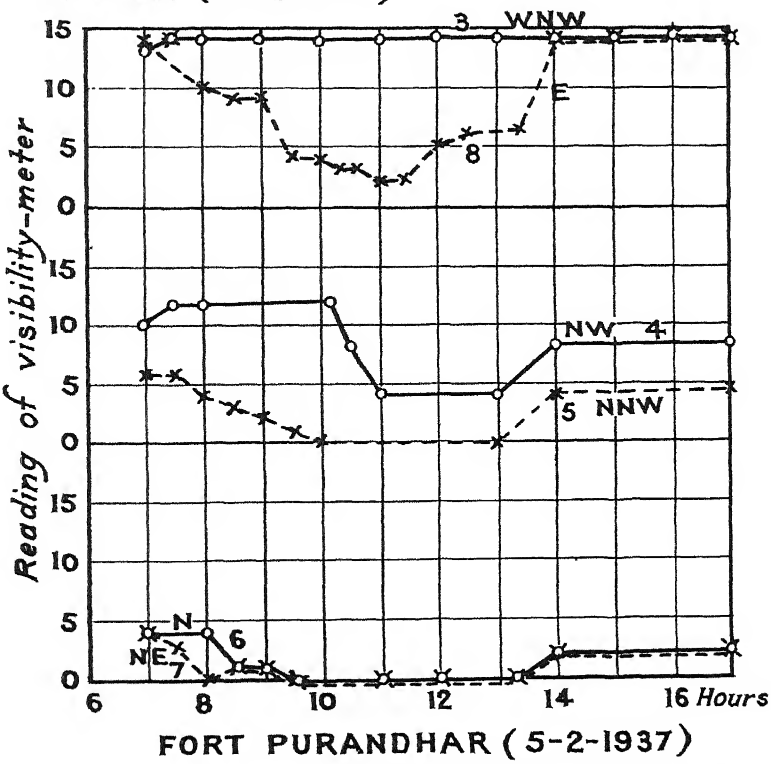


FIG. 7. POSITIONS OF VISIBILITY LANDMARKS AT PURANDHAR.

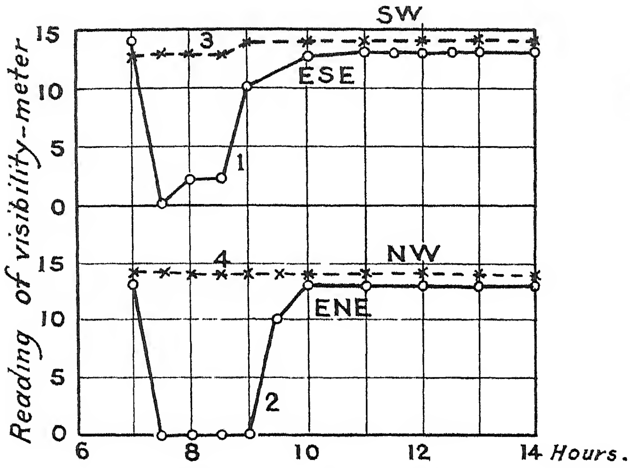


OBJECT No.	HEIGHT ABOVE PLACE OF OBSERVATION
1	275 meters.
2	76 "
3	610 "
4	458 "



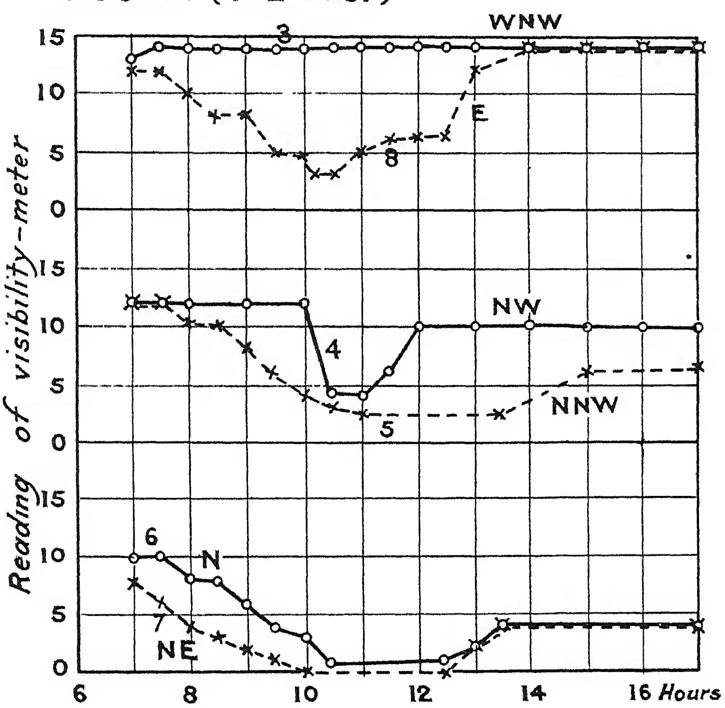
OBJECT No.	HEIGHT ~~ABOVE~~ BELOW PLACE OF OBSERVATION	OBJECT No.	HEIGHT ~~ABOVE~~ BELOW PLACE OF OBSERVATION
3	168 meters.	6	702 meters.
4	473 "	7	473 "
5	702 "	8	625 "

FIG 8. VARIATION OF VISIBILITY WITH TIME



POONA (7-2-1937)

OBJECT No.	HEIGHT ABOVE PLACE OF OBSERVATION
1	275 meters
2	76 "
3	610 "
4	458 "



FORT PURANDHAR (6-2-1937)

OBJECT No.	HEIGHT ~~ABOVE~~ BELOW PLACE OF OBSERVATION	OBJECT No.	HEIGHT ~~ABOVE~~ BELOW PLACE OF OBSERVATION
3	168 meters.	6	702 meters.
4	473 "	7	473 "
5	702 "	8	625 "

FIG. 9. VARIATION OF VISIBILITY WITH TIME.

INDIA METEOROLOGICAL DEPARTMENT

SCIENTIFIC NOTES

Vol. X, No. 116.

A comparison of Cherat surface observations of temperature and humidity at 0800 hrs. L.T with aeroplane observations over the Peshawar plain at the same level

BY

K. L. BHATIA.

(Received on 4th November 1940 and in revised form on 19th July 1941.)

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A comparison of Cherat surface observations of temperature and humidity at 0800 hrs. L.T. with aeroplane observations over the Peshawar plain at the same level.

BY

K. L. BHATIA.

(Received on 4th November 1940 and in revised form on 19th July 1941.)

Abstract.—The paper deals with the comparison of dry-bulb and wet-bulb temperatures and the derived quantities, relative humidities and vapour pressures recorded over a mountain station (Cherat) in the region of Peshawar with the free air values at the same level obtained from aeroplane flights in the neighbourhood. Mean monthly and annual differences have been given and it has been shown that the mountain is cooler than the free air, the mean annual difference being 2·7°F. The wet-bulb temperatures over mountain are higher during November to April and lower during May to October, the mean annual difference being 0·3°F. The relative and the absolute humidities are generally higher over the mountain An analysis of the dry-bulb differences according to season, cloudiness, wind direction and speed has also been given. The results may be useful in estimating free air conditions from mountain observations when aeroplane or balloon observations are not available.

Introduction.

Observations made at mountain observatories are useful because they can give some idea of the free air conditions at the same levels, which is important for understanding the physical processes in the lower levels of the atmosphere. As, however, mountain observations do not exactly represent free air conditions, it is necessary to determine the corrections that are necessary to make them yield free air values with a reasonable degree of accuracy. This can be done by comparing the observations of some representative mountain station with more or less simultaneous free air observations at the same level over a station slightly away from the mountain. Such comparisons have been made in other countries with useful results. This note summarises the results of a similar comparison made of Cherat temperatures and humidities with free air temperatures and humidities at the same height available from aeroplane observations over Peshawar and Risalpur.

Orography.

Cherat Observatory (Lat. 33° 50′ N., Long. 72° 01′ E.) is situated at a height of 4272 feet (1·3 Kms.) at the eastern end of a range of hills running west to east enclosing the southern side of the valley of the Kabul river after it enters the Indian Frontier. The range has an abrupt slope both on the north and the south and slightly increases in height from west to east. Peshawar (Lat. 34° 00′ N., Long.

71° 37′ E.) and Risalpur (Lat. 34° 05′ N., Long. 72° 00′ E.) are situated in the Kabul river valley at a distance of 27 miles apart and 24 and 18 miles respectively from Cherat.

Observations.

The dry-and wet-bulb temperatures at Cherat were obtained from thermometers exposed in a Stevenson screen while free air temperatures were obtained from a strut psychrometer carried on an aeroplane. The psychrometer readings were taken to the nearest degree Fahrenheit and the Cherat readings were also rounded off to the nearest degree for the purposes of study However, the mean temperature differences have been given to the first place of decimal.

Data.

Observations at Cherat were recorded at 0800 hrs. local time (0842 hrs. I.S.T.) daily, but the aeroplane flights at Peshawar and Risalpur were not made daily or at any fixed time. Therefore, for comparison only those days on which aeroplane observations were available within half an hour of the time of morning observations at Cherat were considered. The ascent or the descent readings whichever were nearest to 0800 hrs. L.T. were used. Free air values at 1·3 km. a.s.l. were obtained by interpolation from aeroplane readings taken at every 1,000 feet altimeter level (altimeter correction for temperature being applied) and these were compared with the Cherat observations, the period considered being the six years 1933 to 1938.

Results.

Dry-Bulb Temperature.—The mean monthly differences (free air minus mountain temperature) are given in *Table I* below and the frequency distribution of the differences for the four seasons of the year is shown in *Fig. I.*

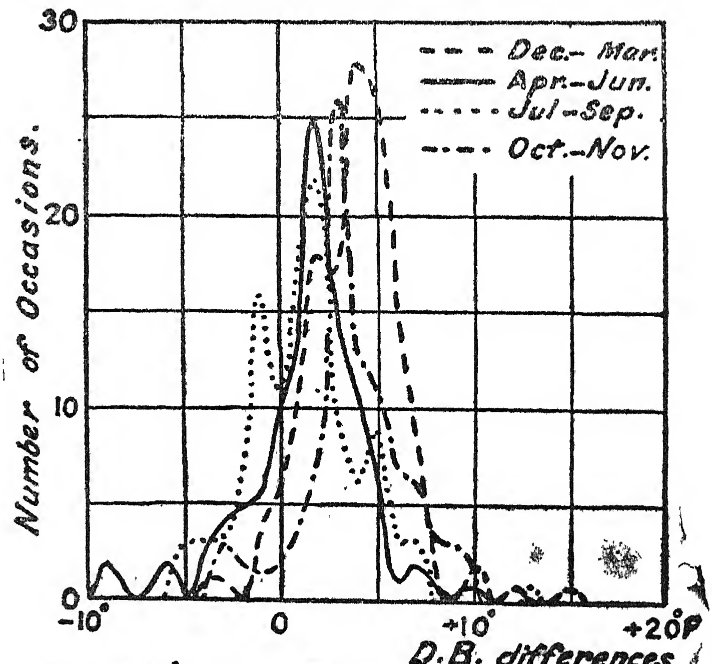

Fig. 1. Free air (P) minus mountain (C) DRY-BULB TEMPERATURES.

TABLE I.

Free Air (Peshawar) minus Mountain (Cherat) temperature °F.

	January.	February.	March.	April	May.	June.	July.	August.	September.	October.	November	December.	Year.
Means .. .	4·6	3·9	3·7	2·0	2·1	0·0	1·0	1·5	1·8	3·9	3·6	3·4	2·7
No. of Observations .	27	35	43	37	39	30	36	32	43	54	36	37	449

It is seen that each of the frequency curves has a sharp peak indicating that the differences are mainly and closely distributed around the mean value and that large deviations from this value are infrequent. Considering the year as a whole mountain temperature is 2·7°F. lower than free air temperature at the same height. The mean difference shows a seasonal variation. It is about 3·8°F. during October to March which is the drier half of the year as judged from the water content of the air and 1·5°F. during April to September which is the moist half of the year. The difference is maximum (4·6°F.) in January and is minimum (0°F.) in June.

The main result is that mountain temperature is lower than free air temperature at the same level particularly in the non monsoon months, and this agrees with the results obtained in other countries quoted by Gold[1] in 'International Kite and Balloon ascents', and summarised in *Table II* below.

TABLE II.

Station.	Height (meters).	Mean difference (°F.)
Brocken	1140	1·6
Ben Nevis	1343	4·7
Zugspitze	2965	2·9

Harwood[2] compared Simla 0800 hrs. local time surface temperature with the free air temperature at the same time of the day over Agra and found the hill station to be warmer. He remarked that this result was opposed to that obtained in Europe and that in view of the large distance between the two stations much weight could not be attached to the results.

The lower mountain temperature in the morning hours as compared to free air temperature at the same height is apparently due to the greater radiational cooling of the mountain and hence of the air in its neighbourhood. The seasonal variation in the difference between mountain and free air temperature may be due to the varying amount of insolation due to the greater interval between sunrise and the time of morning observations in summer than in winter. Greater insolation would have the effect of reducing the positive difference between free air and mountain temperature and if sufficiently active may even make the difference negative. The differences were actually negative on 60 occasions as shown by the frequency curves.

It is to be expected that the difference between free air and mountain temperature would depend on wind direction and speed, cloudiness, etc. *Table III* give the mean values of the differences analysed according to seasons with regard to (1) wind direction, (2) wind speed and (3) cloud amount (low and medium clouds only) at Cherat at the time of observations. Occasions when sky was not discernible due to fog, dust, etc., have not been taken into account.

TABLE III.

Free Air (Peshawar) minus Mountain (Cherat) temperature °F.

Cloud amount (tenths). / Wind speed (Beaufort scale).	NW to NE				SE to SW			
	0—3	4—7	8—10	Mean	0—3	4—7	8—10	Mean
December—March.								
1—3	3·7 *(16)*	2·8 *(9)*	3·7 *(11)*	3·5 *(36)*	4·0 *(4)*	5·2 *(5)*	3·2 *(5)*	4·1 *(14)*
>3	4·2 *(59)*	4·1 *(13)*	1·9 *(9)*	3·9 *(81)*	..	..	—1·0 *(1)*	—1·0 *(1)*
Mean	4·1 *(75)*	3·5 *(22)*	2·9 *(20)*	3·8 *(117)*	4·0 *(4)*	5·2 *(5)*	2·5 *(6)*	3·8 *(15)*
April—June.								
1—3	0·7 *(28)*	2·0 *(3)*	2·5 *(4)*	1·1 *(35)*	1·4 *(12)*	0·2 *(6)*	—4·5 *(2)*	0·5 *(20)*
>3	2·6 *(27)*	2·1 *(7)*	2·7 *(6)*	2·5 *(40)*	2·0 *(1)*	..	2·5 *(2)*	2·3 *(3)*
Mean	1·6 *(55)*	2·1 *(10)*	2·6 *(10)*	1·8 *(75)*	1·5 *(13)*	0·2 *(6)*	—1·0 *(4)*	0·7 *(23)*
July—September.								
1—3	0·7 *(24)*	0·6 *(5)*	3·0 *(1)*	0·8 *(30)*	1·2 *(27)*	1·5 *(6)*	—0·7 *(3)*	1·1 *(36)*
>3	3·6 *(5)*	0·0 *(1)*	—1·0 *(1)*	2·4 *(7)*	..	..	..	..
Mean	1·2 *(29)*	0·5 *(6)*	1·0 *(2)*	1·1 *(37)*	1·2 *(27)*	1·5 *(6)*	—0·7 *(3)*	1·1 *(36)*
October—November.								
1—3	3·2 *(23)*	4·5 *(2)*	3·0 *(3)*	3·3 *(28)*	4·7 *(11)*	..	1·0 *(1)*	4·4 *(12)*
>3	4·0 *(27)*	3·0 *(1)*	—3·0 *(1)*	3·7 *(29)*	..	3·0 *(1)*	..	3·0 *(1)*
Mean	3·6 *(50)*	4·0 *(3)*	1·5 *(4)*	3·5 *(57)*	4·7 *(11)*	3·0 *(1)*	1·0 *(1)*	4·3 *(1*

Calm.

Cloudiness (tenths)	0—3	4—7	8—10	Mean
December—March	..	..	1 0 (1)	1·0 (1)
April—June	2·0 (3)	..	0 5 (2)	1·4 (5)
July—September	2·9 (10)	..	2 0 (1)	2·8 (11)
October—November	4·0 (7)	5·5 (2)	7·0 (1)	4·6 (10)

(Figures in bracket indicate number of observations.)

It is seen that in clear or lightly clouded weather the positive difference increases with the wind speed. There does not appear to be any other marked regularity.

Wet-Bulb Temperature, Relative Humidity and Vapour Pressure.—Wet-bulb temperature and the derived quantities, relative humidity and vapour pressure at Cherat were also compared with the free air values at the same level in the same manner as dry-bulb temperature. The frequency distributions of the differences are given in *Figure 2*, and the mean monthly differences are given in *Table IV* and represented graphically in *Figure 3*, where the dry-bulb differences are also shown for comparison.

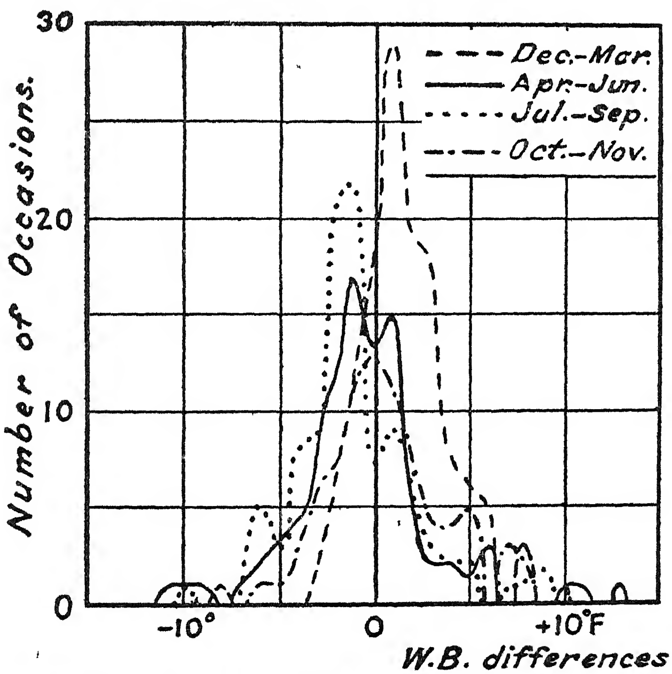

Fig. 2. Free air (P) minus mountain (C) WET-BULB TEMPERATURES.

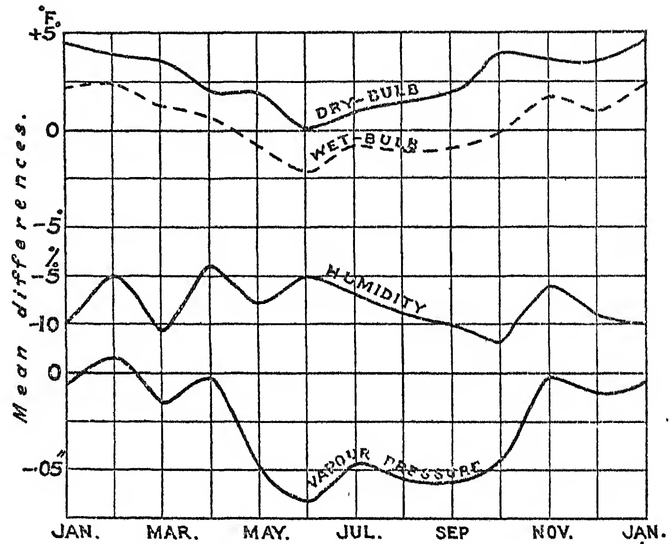

Fig. 3. Free air (Peshawar) minus mountain (Cherat) Mean differences.

TABLE IV.

Free Air (Peshawar) minus Mountain (Cherat) Wet-Bulb temperature, Relative Humidity, and Vapour Pressure.

Month.	Wet-bulb. °F	Relative Humidity. %	Vapour Pressure. in.	No. of Observations.
January	2·3	—10	—·006	22
February	2·4	—5	+ 009	34
March	1·3	—11	—·016	39
April	0·7	—4	—·002	34
May	—0·7	—8	—·047	33
June	—2·2	—5	—·067	27
July	—0·8	—7	—·047	35
August	—1·1	—9	— 054	28
September	—1·1	—10	—·056	39
October	—0·2	—12	—·045	46
November	—1·8	—6	—·001	32
December	1·1	—9	—·011	35
Year	0·3	—8	—·029	404

In the average of the year, there is practically no difference between free air and mountain wet-bulb temperatures but the monthly mean differences* show that during November to April mountain wet-bulb temperatures are lower than free air

*A very small part of this difference is due to the fact that the wet-bulb thermometer in the aeroplane is more ventilated than that at Cherat which is placed in a Stevenson screen.

wet-bulb temperatures while during May to October they are higher. The monthly variation of the differences follows the same trend as that of the dry-bulb. The highest positive difference (2·4°F.) is in February and the negative (-2·2°F.) in June.

Relative humidity over Cherat is always higher than that in the free air at the same level but the differences are small and the annual mean difference is only about 8 per cent.

Vapour pressure over Cherat is in general higher than in the free air at the same level. During November to April, which is the drier half of the year, the differences are small, varying between +·009″ and —·016″ while during May to October which is the more moist part of the year the differences are well marked, ranging from —·045″ to —·067″. The largest difference is in June.

Conclusions.

The conclusions that can be drawn from the paper are that in the region of Peshawar at 8 a.m.

(1) A correction of +4°F. to the mountain temperature is necessary during October to March and of +1·5°F. during April to September to obtain the free air temperature at the same level.

(2) The mountain wet-bulb temperature is lower than the free air wet-bulb temperature during November to April by 1·5°F. and higher during May to October by 1°F.

(3) The relative humidity over the mountain is higher than that in the free air in all months of the year. It does not show any marked regular changes from month to month and the annual mean difference is only 8 per cent.

(4) The vapour pressure over the mountain is generally higher than in the free air. The difference is negligible during the months November to April and is about ·05 in. during the rest of the year.

My grateful thanks are due to Mr. P. R. Krishna Rao for his kind guidance.

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2. W. A. Harwood—*Mem. Ind. Met. Dep.*, **24**, Pt. 6, 182.

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INDIA METEOROLOGICAL DEPARTMENT

SCIENTIFIC NOTES

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BY

A. K. Roy and L. S. Mahalingam.

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Inversion and isothermal layers in the free atmosphere over south India

BY

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Abstract.—The paper contains detailed statistics of inversions and isothermal layers in the free atmosphere over south India up to a height of 10 gkm. above sea level in different months and seasons. A closer study has been made of the comparatively marked inversions at various heights in the different months, and tentative explanations with regard to their origin suggested as far as possible. A brief summary of the main features of the ground inversions at Poona as revealed by the records of thermographs at two different heights has also been added. An examination of the pilot balloon trajectories has shown that the levels of temperature disturbances are usually associated with marked transitions in the wind direction or velocity or both.

INTRODUCTION.

An examination of the thermal structure of the upper atmosphere over any one station would show that the lapse of temperature with height is by no means uniform throughout the troposphere and that sudden changes of lapse-rates, often marking out isothermal or inversion layers of small depth, occur frequently at different levels. These regions of abnormal lapse-rates or "disturbance layers" are generally more frequent in the lower half of the troposphere than in the upper half. The heights at which marked changes in lapse-rates occur, and also those of marked inversions and isothermal layers, are included as a routine in the sounding balloon data published by the India Meteorological Department in the Upper Air Data, Part B (Part 14, prior to 1936). The object of the present paper is to collect together the information in a systematic manner and to study in some detail the characteristics of the disturbance layers over south India, as revealed by the soundings at Poona and Hyderabad in the north and at Madras and Bangalore in the south.

The mean as well as the most frequent heights of these layers in different months and seasons have been determined, and tentative explanations of the occurrence of the more important amongst them suggested, whenever possible.

In order to determine accurately the height of base and the thickness of these layers, and also the temperature difference between the top and bottom of each individual layer, the pressure-temperature (log p, log T) diagram relating to each ascent was scrutinised afresh, and the data tabulated systematically from day to day. For the purpose of this study, data as given by ascents in the evening between 1630 and 1830 hrs. I. S. T. only—the usual hours of sounding balloon ascents in India—have been utilised.

With a view to ensure recovery of instruments, upper air soundings in the north of the Peninsula during the monsoon months June to October were carried out mostly at Hyderabad (Lat. 17° 26′ N, Long. 78° 27′ E) instead of at Poona (Lat. 18° 32′ N Long. 73° 51′ E) where soundings during the remaining months were made. Tables relating to the north Peninsula are therefore based on the combined data of Poona and Hyderabad. Similarly, the tables for the south Peninsula relate to data collected at Madras (Lat. 13° 04′ N, Long. 80° 15′ E) and Bangalore (Lat. 12° 58′ N, Long. 77° 35′ E), the soundings having usually been made at the former station during June to November and at the latter during December to May.

Main features of the distribution with height of disturbance layers over south India.—The following table shows the distribution with height of isothermal and inversion layers at various levels between 1 and 10 gkm. above sea level, based on data of 161 ascents at Poona and Hyderabad. Owing to the blur caused by the jerks which the meteorographs receive on landing, the greater part of the sounding balloon record in the lowest half kilometre above ground, that is, up to about 1 km. above sea level in the case of Poona—Hyderabad, is often lost, and data up to 1 gkm. have therefore been omitted from the discussion. Ground inversions in the evening are however a common feature, especially during the winter months, as can be seen from the records at Poona of a thermograph near the ground and another installed on the tower of the observatory about 120 ft. high. A brief account of the main features of these inversions is added in a later paragraph.

TABLE I(*a*).

Distribution of isothermal and inversion layers at various levels above Poona-Hyderabad.

Height in gkm	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10	Total number of soundings.
Number of inversions and isothermal layers.	15	63	53	52	37	26	22	17	15	161

The table above shows that the disturbance layers are most frequent at 2-3 gkm level, and that the frequency decreases gradually as we go to higher levels. The large and sudden fall in frequency at the next lower level, 1-2 gkm., is noteworthy. Features similar to the above have been noticed by Chang Wang Tu * in his analysis of the distribution of inversions with height over Nanking and Peiping.

Table I (*b*) gives similar information relating to the south of the Peninsula, as gathered from 155 soundings at Madras and Bangalore.

*Chang Wang Tu,—Mem. Nat. Res. Inst. Met. Acad. Sinica. **12**, No. 2.

TABLE I (*b*).

Distribution of isothermal and inversion layers at various heights above Madras-Bangalore.

Height in gkm	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10	Total number of soundings.
Number of isothermal and inversion layers.	37	59	55	44	44	28	17	13	4	155

It is seen from the table that, taking the year as a whole, the disturbance layers, over the south Peninsula also are most frequent at 2-3 gkm level and that the frequency decreases progressively with height, the number being only 4 out of 155 at the topmost or 9-10 gkm. level. The frequency at the lowest, *i.e.*, 1-2 gkm. level is, however, much greater in this case than over the north Peninsula.

PART A.

Monthly mean frequencies of occurrence, mean depths and other details relating to disturbance layers over the north Peninsula.—*Table II* (*a*) gives the percentage frequencies of occurrence in different months of isothermal and inversion layers above Poona-Hyderabad at various levels, in steps of 1 gkm., up to a height of 10 gkm. above sea level. The disturbance layers are found to be most frequent between 2 and 3 gkm. during the months November to January. The frequency at this level decreases abruptly in February, when it is only 9 per cent. as against 62 per cent in the previous month. The level of maximum frequency is at a height of 5 to 6 gkm. during February to April, but lowers gradually again to 4-5 gkm. during May to July, and 3-4 gkm. in August. In September, the frequency of occurrence no where exceeds 30 per-cent. and is the same at all heights between 2 and 6 gkm. The disturbance layers are quite frequent in October between 2 and 4 gkm., the maximum of 63 per cent occurring at the 2-3 gkm. level.

In *Table III* (*a*) are given the monthly mean values of the depth in metres of the disturbance layers at various levels over the north Peninsula, while *Table IV* (*a*) shows the mean temperature difference between the top and bottom of these layers at each level. The mean heights of the base of the disturbance layers and the mean temperatures at those heights are given in *Tables V* (*a*) and *VI* (*a*) respectively. It should be noted that the mean values as given in all these tables are the averages based on the number of occasions on which isothermal or inversion layers occurred at the various levels, and not on the total number of soundings at these heights. In order therefore to judge the quantitative influence of the disturbance layers on the mean lapse-rates at different levels it is necessary that the values as given in *Tables III* (*a*) and *IV* (*a*) should be considered with due regard to the frequency values in *Table II* (*a*). For instance, an examination of the tables shows that the disturbance layers which occur at the 2-3 gkm level on 56 to 77 per cent. occasions during the months November to January have a mean thickness of about 0·3 gkm., with the temperature increasing by about 1°C from the bottom to the top, instead of falling by about 1·5 to 2°C according to the usual lapse-rate. The presence of the disturbance layers at this level during the above months thus produces a marked effect on the thermal structure of the atmosphere between 2 and 3 gkm. On the other hand, although the mean thickness of the disturbance layer, when this happens to be present at the 6-7 gkm. level in December, is as much as 490 metres, its effect, on the mean, on the vertical temperature distribution between 6 and 7 gkm. is much less pronounced than in the former case as such a disturbance layer is noticed in only 13 per cent. cases.

TABLE II (*a*).

Percentage frequency of occurrence of disturbance layers at various heights (Poona-Hyderabad).

Months. \ Height (gkm)	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
January ..	3	62	24	28	7	17	14	10	10
February ..	0	9	21	29	37	29	13	18	18
March ..	0	9	27	36	45	9	18	36	18
April ..	15	8	15	15	31	0	8	0	15
May ..	21	11	5	37	28	6	18	19	0
June ..	0	20	0	60	0	0	0	0	0
July ..	11	11	44	44	11	22	0	0	11
August ..	0	30	50	30	10	10	20	10	0
September ..	0	25	30	30	30	10	25	5	5
October ..	6	63	56	31	0	19	0	0	6
November ..	31	77	38	11	23	11	17	8	0
December ..	13	56	37	6	6	13	0	0	7

TABLE III (*a*).

Mean depth in metres of disturbance layers with base at various levels.

Months. \ Height (gkm)	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
January ..	220	260	190	280	250	500	150	290	430
February ..	..	270	250	200	190	240	340	250	240
March ..	..	120	240	370	200	390	180	190	110
April ..	150	30	220	190	290	..	..	..	190
May ..	190	330	160	270	260	220	230	210	..
June ..	..	300	..	180	..	..	..	..	..
July ..	750	110	210	370	150	130	..	..	360
August ..	..	170	150	240	180	120	220	170	..
September ..	..	250	250	250	220	210	200	130	110
October ..	150	190	170	190	..	190	..	..	70
November ..	240	350	180	250	180	160	250	150	..
December ..	150	370	270	190	80	490	..	..	110

TABLE IV (*a*).

Mean rise of temperature (°C) from the base to the top of the disturbance layers at various levels.

Height (gkm) / Months.	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
January	1·4	0·9	0·8	0·8	0·4	0·8	0	0·6	0·3
February ..	..	1·3	0·6	0·7	0·5	0·6	0	0·2	1·2
March .	..	1·0	0·3	2·0	0·6	0	0	0	0
April ..	0·4	1·3	1·3	0·4	1·1	.	..	..	0
May ..	0·6	0	0	0·3	0·6	0	0·8	0·1	..
June ..	.	0	..	0·5	..	.	..	..	..
July ..	0·5	0	0·3	0·3	0	0·2	.	..	2·5
August ..	..	0·5	0·2	0·6	0·2	0·2	0	0	..
September ..	..	0·3	0·2	0·4	0·5	0	0·3	1·3	0
October .	0·2	0·9	1·1	0·1	..	0	..	..	0·2
November ..	0·3	0·9	0·9	0·8	0·1	0	0·6	0	..
December ..	1·0	1·2	1·7	0·5	0·2	0	..	..	0

TABLE V (*a*).

Mean height in gkm. of base of the disturbance layers at various levels.

Height (gkm) / Months.	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
January ..	1·65	2·64	3·35	4·61	5·45	6·46	7·57	8·58	9·64
February ..	..	2·62	3·47	4·37	5·41	6·27	7·83	8·38	9·45
March ..	..	2·51	3·87	4·56	5·44	6·59	7·51	8·53	9·45
April ..	1·72	2·37	3·73	4·33	5·29	..	..	..	9·31
May ..	1·80	2·05	3·38	4·57	5·25	6·88	7·37	8·55	..
June ..	..	2·34	..	4·07	..	.	..	..	..
July ..	1·27	2·04	3·52	4·66	5·38	6·17	..	..	9·42
August ..	..	2·73	3·52	4·53	5·50	6·13	7·20	8·52	..
September ..	..	2·61	3·53	4·62	5·33	6·46	7·47	8·17	9·19
October ..	1·68	2·46	3·43	4·52	..	6·39	..	..	9·70
November ..	1·45	2·55	3·52	4·40	5·48	6·31	7·16	8·82	..
December ..	1·57	2·56	3·62	4·98	5·00	6·27	..	..	9·46

TABLE VI (*a*).

Mean temperature (200° A +) at the base of disturbance layers at different levels.

Height (gkm) / Months.	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
January ..	89·0	81·6	78·6	70·0	63·7	59·8	48·9	40·8	35·7
February ..		79·7	75·5	69·3	64·5	61·2	50·5	46·7	42·4
March ..	.	82·0	73·6	70·6	65·0	60·8	51·5	43·7	36·1
April ..	94·6	87·9	76·1	74·8	67·3	..	.	..	4·05
May ..	92·3	89·8	82·0	72·5	68·4	55·2	56·6	47·6	..
June ..	..	84·8	..	76·2	..	..	..	..	..
July ..	86·4	88·6	79·6	72·5	70·1	64·3	..	..	44·5
August ..	..	82·1	76·7	74·0	71·5	68·5	62·0	54·6	..
September ..	..	84·1	79·1	74·1	69·7	62·3	57·7	51·9	46·0
October ..	89·6	84·6	79·7	74·7	..	63·0	.	..	41·2
November ..	89·6	82·4	77·8	74·7	65·1	61·3	57·7	46·0	..
December ..	88·7	81·2	78·6	70·0	63·7	59·8	48·9	40·8	35·7

Seasonal characteristics of inversion and isothermal layers.—With a view to study the main characteristics of the disturbance layers in the different seasons, the figures in *Tables II (a)* to *IV (a)* have been grouped together under the three main seasons, winter (November to January), spring and summer (February to May) and southwest monsoon (June to October). These seasonal averages together with the annual means are shown in *Tables VII (a)* to *IX (a)*. The above division differs somewhat from the one adopted usually, and particularly in that the month of February has been grouped under spring and summer and not under winter. The reason why this has been done is that from the point of view of frequency distribution as shown in *Table II (a)* the month of February appears to show characteristics more akin to those of March to May than to those of the cold season, November to January.

TABLE VII (*a*).

Seasonal and annual means of the percentage frequency of disturbance layers at various levels (Poona-Hyderabad).

Height (gkm) / Seasons.	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
Winter (Nov. to Jan.).	12	64	31	19	10	16	11	7	7
Spring and Summer (Feb to May).	9	9	16	30	35	14	14	18	13
Southwest monsoon (June to Oct.)	3	33	40	35	13	13	12	3	5
Year	8	34	29	28	20	14	12	10	8

TABLE VIII (*a*)

Seasonal and annual means of the depth (metres) of disturbance layers.

Height (gkm) / Seasons.	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
Winter ..	210	310	270	270	190	400	190	260	350
Spring and Summer.	170	210	240	250	220	260	260	220	190
Southwest monsoon.	450	200	190	250	210	180	210	150	180
Year ..	220	270	230	250	220	280	220	210	230

TABLE IX (*a*).

Seasonal and annual means of the temperature difference (°C) between the base and the top of the disturbance layers.

Height (gkm) / Months.	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
Winter ..	0·6	1·0	1·1	0·8	0·2	0·4	0·2	0·5	0·3
Spring and Summar.	0·5	1·0	0·6	0·8	0·7	0·4	0·3	0·1	0·5
Southwest monsoon.	0·3	0·6	0·6	0·4	0·3	0·1	0·2	0·8	0·9
Year ..	0·5	0·9	0·7	0·6	0·5	0·3	0·3	0·3	0·5

An examination of the above tables shows that the frequency of isothermal or inversion layers during the winter months has a pronounced maximum at 2-3 gkm level with a weak secondary maximum between 6 and 7 gkm The lower disturbance layer is about 0·3 gkm thick on the average, and shows a counter lapse of temperature of about 3°C/ gkm. The mean thickness of the upper disturbance layer is about 0·4 gkm but the inversion of temperature in this layer is less marked, the inverted lapse-rate being only about 1°C/gkm. During February to May, the frequency distribution with height shows a rather flat maximum between 4 and 6 gkm, with an indication of a probable secondary maximum at 8-9 gkm level. The inversion is again found to be more marked in the lower disturbance layer where the rate of temperature increase is about 3°C/gkm. The upper disturbance layer, on the mean, shows an isothermal structure and the mean thickness of both disturbance layers is about 0·25 gkm. During the monsoon season, June to October, the frequencies at all the three levels between 2 and 5 gkm are very nearly the same, *viz.*, between 33 and 40 per cent., with just an indication of a slight maximum of 40 per cent at the 3-4 gkm level. A secondary maximum at a higher level is not noticeable in this season. Distrubance layers of the monsoon months are in most cases less deep than in the other two seasons The inversion of temperature is also generally less marked except between 8 and 10 gkm where inversions, although they occur very infrequently and extend over a comparatively shallow layer, are quite well pronounced when they happen to be present.

The vertical course of the mean magnitude of the temperature reversal, as indicated in *Table IX* (*a*), shows that, on the annual mean, it is maximum at 2-3 gkm level, the mean value at this level being 0·9°C as against 0·5°C at 1-2 gkm, decreasing gradually to 0·3°C at 8-9 gkm. A slight rise is noticed at the topmost level where the mean magnitude of the temperature reversal is 0·5°C as compared with 0·3°C at the next lower level. An examination of the seasonal values further shows that up to a height of 5 gkm the maximum temperature reversal occurs in the winter months. At higher levels, *viz.*, between 5 and 8 gkm, the maximum is seen to occur during the period February to May, while at still higher levels, that is, between 8 and 10 gkm, the mean rise in termperature is highest during the monsoon season. Again, *Table VIII* (*a*) shows that as in the case of temperature reversal, the vertical extent or the depth of the disturbance layer has a tendency to decrease with elevation. The fall is, however, not so regular as in the former case, and two maxima are noticeable, one at 2-3 gkm and the other at 6-7 gkm level. These characteristics are very similar in their main features to those found by Peppler* from an examination of the kite data of the Lindenberg observatory up to a height of about 4500 m.

Disturbance layers with inversion of temperature of 1·5° or more.—In *Table X* (*a*) below are given the frequencies of inversions of 1·5° or more at various levels above Poona-Hyderabad in different months of the year. Of the 47 such inversions 37 showed a temperature rise of 1·5° to 2·9°, 8 of 3° to 4·9° and 2 only of 5° or more, showing that conditions for the development of inversions with a large increase of temperature with height are rarely fulfilled in the troposphere. The mean thickness of the inversion layers of the three different groups is found to be 0·28, 0·21 and 0·12 gkm respectively, which shows that the more pronounced the inversion the less usually is its vertical extent.

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*W. Peppler,—Beitr. Phys. frei. Atmos. 11. Pt. 3.

TABLE X (*a*).

Inversions of 1·5°C or more—(Poona-Hyderabad).

Height (gkm) / Months.	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
January ..	..	4	1	1	..	1	..	.	..
February ..	.	1	..	1	1	1	..	..	1
March .	..	..	..	3	2	..	..	..	..
April .	..	..	1		1	..	..	..	..
May ..	..	..	.	..	1	..	1	..	..
June ..	..	1	..	..	.	..	..	..	.
July ..	..	..	.	..	..	..	..	..	1
August .	..	..	.	1	..	..	1	..	.
September ..	..	1	..	..	1	..	1	..	.
October	.	3	1	..	..	.	..	..	..
November ..	..	4	1	1	..	..	..	..	..
December .	..	6	3	..	..	..	..	..	..
Year ..	..	20	7	7	6	2	3	..	2

It is seen from the above table that, taking the year as a whole, the inversions of 1·5° or more occur mostly as 2-3 gkm level and are very rare at heights above 6 gkm. A complete absence of such inversions between 1 and 2 gkm. is noteworthy. The table further shows that inversions of this kind up to a height of 4 gkm occur mostly during the winter months, November to January, are present on a few occasions in October but are rare during the other months. From an examination of the cloud data at the time of ascents which showed marked inversions at these lower heights, it is seen that in the majority of cases the sky was clear, or if some cloud was present, it was generally at a level far removed from that of the inversion layer For example, out of the 20 cases in which an inversion of 1·5° or more was present at the 2-3 gkm level, sky was practically clear in 13 instances, cumulus of small amount with or without other clouds was present on 5 occasions and cirrus (amount 1 or 2) in the remaining two cases. It would thus appear that inversions in the lower levels during winter months over Poona-Hyderabad cannot in most cases be explained as being due to the presence of cloud layer. Preponderance of clear skies would also suggest that in the majority of cases the inversions are not the result of a warm humid air mass over-running colder air. Again the complete absence of such inversions at 1-2 gkm level and the fact that some of the ascents carried out during midday also reveal the existence of inversions at these heights show that these cannot be accounted for merely by the effect of ground cooling by radiation.

In his paper on " The thermal layering of the atmosphere ", Peppler has stated that in winter, when anticyclones prevail, the simultaneous cooling by radiation of the lower air mass and the dynamical warming of the upper air by subsidence play

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the greatest role in the formation of strong inversions. It is thought that marked inversions above Poona in winter months, particularly those at 2-4 gkm levels, have a more or less similar origin Poona is situated in the peripheral regions of the anti-cyclone which prevails in this season over the central parts of India. The lower cold layers of this permanent anticyclone form a relatively inactive mass, while the upper air layers sink and spread over the lower air. The descending anticyclonic movement of the air continues up to the top of the relatively stagnant air below, and at this height we have a temperature discontinuity between the lower cold air mass and the dynamically heated air above. A comparison of saturation potential temperatures at heights slightly above and below these inversions shows that the values in most cases are very nearly the same lending support to the hypothesis that inversions in this season develop mostly in one and the same air mass. February and March inversions at lower levels also probably have a similar origin. The reason why the inversions during this season form at higher levels than in the winter months is that the anticyclonic descent of the air is prevented from reaching lower heights by the greater convective activity in the lower layers. Of the 10 marked inversions which occurred at heights above 3 gkm during the period April to October, 7 were associated with cloudy weather. It is probable that April and May inversions form mainly at the top of the thunder clouds which develop occasionally in the afternoons and that the monsoon inversions, particulary those at heights of 4 to 6 gkm, originate at the boundary separating the fresh and cool monsoon air from the west form the comparatively warm old monsoon air from the east or the dry current of air from northwest India.

Disturbance layers of depth 0·3 gkm. or more.—Out of the total of 300 inversions or isothermal layers noticed above Poona-Hyderabad during the period under examination, 85 or 28 per cent. only had a depth of 0·3 gkm or more. The vertical distribution of these disturbance layers in different months is shown in *Table XI (a)*.

TABLE XI (*a*).

Disturbance layers with vertical extent of 0·3 gkm or more (Poona-Hyderabad).

Height (gkm). / Seasons.	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
January	0	7	2	2	1	4	0	1	2
February	0	1	0	0	2	1	2	1	0
March	0	0	1	3	0	0	0	1	0
April	0	0	1	0	1	0	0	0	0
May	1	1	0	2	2	0	1	0	0
June	0	2	0	0	0	0	0	0	0
July	1	0	0	2	0	0	0	0	0
August	0	0	1	0	0	0	0	0	0
September	1	3	2	4	2	0	1	0	0
October	0	1	3	0	0	1	0	0	0
November	0	8	3	1	0	0	1	0	0
December	0	5	1	0	0	2	0	0	0
Year	3	28	14	14	8	8	5	3	2

The table shows that, as in the case of inversions of 1·5° or more, those disturbance layers of large vertical extent are, on the annual mean, most frequent at 2-3 gkm level and that the frequency falls off rather rapidly as we go to higher levels.

Of the 87 disturbance layers shown in the above table, 66 (76%) were 0·3 to 0·5 gkm deep, 16 (18%) had a vertical extent of 0·5 to 0·7 gkm and 5 (6%) only were more than 0·75 gkm deep. All the 5 disturbances of pronounced depth were either isothermal or showed only a weak inversion. Also, while the mean magnitude of the temperature reversal in the case of the first group was 1°C, that of the second group (0·5 to 0·7 gkm deep) was 0·7°C only, showing that on the average, the greater the depth the less pronounced is the inversion. This is what is to be expected, for, it is at the time when an inversion first develops either at the boundary of two air masses or in the same homogeneous airmass and before mixing begins as a result of turbulence that the inversion is most pronounced The discontinuity at this moment is most sharp and the disturbance layer least deep. With the progress of time, mixing by turbulence tends to reduce the temperature difference between the air layers above and below and what was a sharp discontinuity at the time of formation becomes, as the inversion becomes old, a diffused layer of finite thickness with a smaller contrast in temperature between the top and the bottom.

The effect of disturbance layers on the observed mean temperature gradient.— The temperature gradient as deduced from the difference between the mean temperatures at any two successive levels is the resultant effect of a fall of temperature over the portion of the atmosphere in which the lapse of temperature obeys the normal law and a rise or uniformity of temperature over the portion occupied by the disturbance layer. The mean gradient as obtained from the temperature difference between two standard geo-kilometre levels does not, therefore, give one the correct lapse-rate in the region outside the disturbance layer. The latter quantity which, in other words, gives what the mean temperature decrease between the levels in question would be if no inversions or isothermal layers were present, can however, be calculated easily with the help of the data of mean frequencies, magnitudes of temperature reversal and depths of the disturbance layers as given in *Tables II (a)* to *IV (a)*. The values have been calculated for three representative months, November, March and July and are given in *Table XII (a)*. The figures in the rows marked (B) give the differences of inversionless and real temperature decrease for the same layers.

TABLE XII (*a*).

(*Poona-Hyderabad*).

	Height (gkm).	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
November	(A) Calculated mean temperature gradient (°C/km) if no inversion of isothermal layer was present.	8·3	7·3	5·7	6·2	6·6	6·2	7·3	8·0	7·9
	(B) Difference between (A) and the actual mean gradient.	0·7	2·7	0 7	0·3	0·3	0·1	0·4	0·2	0·0
March.	(A) .. .	8·2	10·3	8·3	6·2	6·3	6·0	7·7	7·5	7·8
	(B)	0·0	0·1	0·7	1·6	0·4	0·3	0·2	0·5	0·2
July.	(A)	7·1	5·5	5·9	6·9	6·2	5·0	6·4	7·5	8·1
	(B)	0·6	0·1	0·6	1·2	0·1	0·2	0·0	0·0	0·6

The maximum difference amounting to 2·7° occurs in winter (November) at 2-3 gkm level, and the difference decreases rapidly at higher levels. In March (representing spring and summer) and in July (southwest monsoon season), the effect of the disturbance layers on the mean temperature gradient is most marked between 4 and 5 gkm.

Fig. 1 shows the mean height-temperature curves for Poona-Hyderabad for the three months March, July and November, the diagrams being drawn after giving due weight to the effect of the disturbance layers at each level. These curves which reveal a laminated structure of the atmosphere with well expressed discontinuities show at a glance the relative importance of the disturbance layers at various levels and represent the thermal structure of the atmosphere in a greater detail than a height-temperature curve based on values at standard heights only.

Ground inversions at Poona.—Surface inversions arising out of the radiational cooling of the ground are of daily occurrence at Poona from evening till morning except in the monsoon season and are particularly well marked during the dry clear months, December to March. The table below summarises the main features of the inversions, being based on a study of a year's records of two thermographs, one at a height of 4 ft. above ground and the other on the top of the tower about 120 ft. high.

TABLE XIII.

Ground inversions above Poona.

Months.	Jan.	Feb	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Frequency of inversions..	100	100	100	100	100	80	*Nil.*	*Nil*	*Nil.*	97	97	100
Mean time of commencement.	1900 hrs.	1900 hrs.	2100 hrs.	2100 hrs.	2230 hrs.	2300 hrs.	..	..	.	1930 hrs.	1800 hrs.	1800 hrs.
Mean time of disappearance.	0945 hrs.	0930 hrs.	0900 hrs.	0830 hrs.	0830 hrs.	0700 hrs.	.	..	..	0900 hrs	0900 hrs.	0900 hrs.
Time of occurrence of strongest inversion.	Mid-night.	Mid-night.	0400 hrs.	0500 hrs.	0600 hrs	0600 hrs.	.	.	..	0400 hrs.	0200 hrs.	0200 hrs.
Mean magnitude of the temperature reversal at the time of strongest inversion.	7°F	7°F	7°F	6°F	4°F	1·3°F	..	..	..	4°F	6·5°F	8°F

The table shows that the duration of the inversions is the longest during the winter months and that, on the mean, the maximum temperature reversal occurs in the month of December. It is further seen that while during the period April to June the inversion is most marked near about the minimum temperature epoch, the intensity of the inversion during November to February is the strongest between midnight and 0200 hrs., that is, a few hours before the occurrence of the minimum.

PART B.

Disturbance layers over the south Peninsula as shown by soundings at Madras and Bangalore.—Table II (b) to VI (b) give details of the layers of temperature disturbances over Madras-Bangalore, similar to those given in the corresponding tables for Poona-Hyderabad. It is seen from *Table II (b)* that the level of maximum frequency (62%) of the disturbances is at 1-2 gkm in the month of November It rises to 2-3 gkm in December and January, the frequency at this level being as high as 86 % in December and 69 % in January. The frequency of disturbances in January at 3-4 gkm is however much greater and that at 1-2 gkm much smaller than at the corresponding levels in December, showing that inversions and isothermal

layers tend to form at greater heights as the season progresses. This tendency continues during the next two or three months, and the level of maximum frequency is found to occur at 3-4 gkm in February, at 5-6 gkm in March and at 4-5 gkm in April. Combining the frequencies at the lowest two levels it is seen that the disturbance layers at these heights occur in 100 per cent. cases in November and December and in 85 per cent. cases in January. The frequency decreases to 56 per cent. in February and to 23 per cent. only in the month of March. Thus an inversion or isothermal layer between 1 and 3 gkm is a permanent feature of the thermal structure of the atmosphere over the south Peninsula during November and December and is present on most days in the month of January also. During May to October, the disturbance layers are rather infrequent at all levels except between 2 and 4 gkm in August and between 3 and 5 gkm in September when an inversion or isothermal layer is observed in about 50 per cent. cases.

Turning to *Table IV* (*b*) it is seen that inversions are most prominent in the month of December between 1 and 3 gkm where a disturbance layer shows on the mean a rise in temperature of 1·7°C from the bottom to the top. Inversions are also quite well pronounced at 2-3 gkm level in January and February. The value of 1° at 1-2 gkm in July is the effect of just one inversion and does not, on the mean, have any appreciable influence on the temperature gradient at that level.

TABLE II (*b*).

Percentage frequencies of disturbance layers at various heights (Madras-Bangalore).

Months. \ Height (gkm).	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
January	23	69	62	23	23	8	46	8	8
February	0	56	67	44	33	22	11	22	0
March	8	15	38	31	54	17	8	0	0
April	19	9	9	64	36	19	27	27	19
May	11	0	0	22	22	33	0	11	0
June	0	33	33	11	11	33	11	0	0
July	8	8	31	31	31	31	23	0	0
August	41	47	47	24	35	29	0	18	0
September	7	40	47	47	33	20	7	13	7
October	0	36	27	18	10	10	0	0	0
November	62	38	33	20	25	0	0	6	0
December	57	86	21	14	21	14	7	0	0

TABLE III (*b*).

Mean depth in metres of disturbance layers with base at various levels.

Months \ Height (gkm).	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
January	340	300	210	440	210	370	160	90	70
February	..	350	410	470	270	250	190	270	..
March	110	180	190	210	220	250	70	..	..
April	150	100	160	260	220	210	180	190	170
May	210	..	.	140	120	150	..	310	..
June	..	240	110	130	280	190	180	.	..
July	220	210	110	260	220	190	210	..	..
August	230	140	120	150	190	150		70	..
September	90	160	230	190	300	220	80	170	230
October		320	170	130	240	160		..	..
November	170	200	110	170	210	..	.	350	..
December	330	270	450	230	180	350	250	..	..

TABLE IV (*b*).

Mean rise in temperature (°C) from the base to the top of the disturbance layers at various levels.

Months. \ Height (gkm)	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
January	0·4	1·3	0·2	0·1	0·3	0·0	0·5	0·2	0·4
February	..	1·2	0·4	0·5	0·0	0·7	0·0	0·1	..
March	0·6	0·7	0·8	0·6	0·5	0·1	0·0	..	..
April	0·1	0·0	0·3	0·1	0·1	0·4	0·1	0·0	0·0
May	0·0	..	..	0·9	0·4	0·2	..	0·0	..
June	.	0·5	0·4	0·0	0·0	0·3	0·0	..	..
July	1·0	0·0	0·4	0·5	0·2	0·5	0·0	..	..
August	0·1	0·2	0·4	0·6	0·4	0·3	..	0·7	..
September	0·1	0·4	0·5	0·4	0·0	0·5	0·3	0·0	0·0
October	..	0·1	0·1	0·3	0·4	0·0	..	..	..
November	0·5	0·7	0·2	0·1	0·1	..	..	0·0	..
December	1·7	1·7	1·2	0·0	0·1	0·2	1·0	..	..

TABLE V (*b*).

Mean height in gkm of the base of the disturbance layers at various levels

Months. \ Height (gkm).	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
January	1·64	2·38	3·31	4·30	5·46	6·73	7·45	8·33	9·65
February	..	2·67	3·22	4·29	5·45	6·51	7·53	8·29	..
March	1·91	2·22	3·13	4·27	5·57	6·57	7·76	..	..
April	1·68	2·42	3·94	4·46	5·38	6·65	7·71	8·45	9·27
May	1·75	..	..	4·67	5·29	6·55	..	8·33	..
June	..	2·57	3·29	4·18	5·97	6·47	7·12	..	..
July	1·52	2·87	3·44	4·38	5·54	6·43	7·57	..	..
August	1·68	2·44	3·40	4·62	5·49	6·41	..	8·43	..
September	1·54	2·48	3·36	4·55	5·27	6·71	7·46	8·11	9·46
October	..	2·41	3·71	4·42	5·24	6·62		..	..
November	1·53	2·51	3·43	4·47	5·19		..	8·37	..
December	1·76	2·39	3·32	4·39	5·56	6·27	7·74	..	..

TABLE VI (*b*)

Mean temperature (200° A+) at the base of the disturbance layers at various levels.

Months. \ Height (gkm).	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
January	87·5	83·6	79·7	73·2	67·5	57·8	51·9	47·8	38—0
February	..	81·4	79·2	73·5	67·7	61·7	52·2	48·9	..
March	86·4	86·0	77·5	72·7	64·9	61·1	46·8	..	..
April	93·1	87·2	73·5	72·8	67·5	60·0	52·3	47·6	42·3
May	94·2	..	..	70·0	68·9	61·9	..	42·4	..
June	..	84·9	80·9	72·2	66·0	62·8	60·4	..	..
July	92·5	85·8	79·6	75·0	68·3	62·2	56·6	..	..
August	91·3	85·8	79·5	75·0	68·7	64·0	..	50·3	..
September	91·9	85·9	79·0	73·4	70·1	61·4	56·0	51·9	43·4
October	..	85·5	77·9	71·7	68·9	61·0	..	..	..
November	89·0	84·4	79·6	74·1	70·1	..	..	48·2	..
December	87·0	83·5	77·6	75·3	65·3	58·7	50·0	..	..

Seasonal characteristics of disturbance layers over south Peninsula.—The monthly mean frequencies, magnitudes of temperature reversal and depths of disturbance layers, as given in *Tables II* (b) to IV (*b*) have been grouped together under three main seasons northeast monsoon or winter (November to February), summer (March to May) and southwest monsoon (June to October). These seasonal values together with the annual means are given in *Tables VII* (*b*) to *IX* (*b*).

TABLE VII (*b*)- (*Madras-Bangalore.*)

Seasonal and annual means of the percentage frequency of disturbance layers at various levels.

Height (gkm) / Seasons.	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
Northeast monsoon or winter (Nov-Feb).	42	60	42	23	25	9	15	8	2
Summer (March-May) . . .	12	9	18	40	40	22	12	12	6
Southwest monsoon (June-October)	14	34	38	28	27	25	8	8	2
Year	24	38	35	29	29	18	11	9	3

TABLE VIII (*b*).

Seasonal and annual means of the depth (metres) of disturbance layers.

Height (gkm) / Seasons.	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
Northeast monsoon or winter (Nov - Feb.)	240	270	260	330	220	310	170	210	70
Summer (March-May)	150	150	190	230	200	200	150	220	170
Southwest monsoon (June-October)	210	190	150	190	240	180	180	230	230
Year	220	230	200	240	230	210	170	220	160

TABLE IX (*b*).

Seasonal and annual means of the temperature difference (°C) between the base and top of the disturbance layers.

Height (gkm) / Seasons.	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
Northeast monsoon or winter (Nov.-Feb.).	0·9	1·3	0·4	0·2	0·1	0·4	0·5	0·1	0·4
Summer (March-May)	0·2	0·5	0·7	0·4	0·2	0·2	0·1	0·0	0·0
Southwest monsoon (June-October)	0·2	0·3	0·4	0·2	0·4	0·4	0·4	0·4	0·0
Year	0·7	0·9	0·4	0·3	0·2	0·3	0·3	0·2	0·1

The tables show that, as in the case of the north Peninsula, the disturbance layers over the south Peninsula also occur most frequently at 2-3 gkm level during the winter months. The disturbances at this level generally take the form of well pronounced inversions with a mean thickness of 0·27 gkm and a counter lapse of temperature of about 5°C./km. They are also fairly frequent in this season at the two adjoining levels, *viz.*, 1-2 and 3-4 gkm, where they are seen to occur in more than 40 per cent. cases The frequencies at all the three levels fall off rapidly to a minimum in summer when the level of maximum frequency rises to a height of 4-6 gkm During June to October, the disturbance layers become somewhat more frequent than in summer at 2-3 and 3-4 gkm levels, and the maximum frequency of 38 per cent. actually occurs at the latter height. The vertical course of the mean magnitude of the temperature reversal show, on the annual mean, the same characteristics as over the north Peninsula, *viz.*, the maximum value at 2-3 gkm and a gradual decrease at higher levels. This annual feature is influenced largely by the conditions prevailing in the winter season when marked inversions are of frequent occurrence at the height of 2-3 gkm. The depth of the disturbance layer does not, on the annual mean, show any systematic variation with height, the mean values at most levels lying between 200 and 230 metres

Inversions of 1·5°C or more over Madras-Bangalore—Out of the total of 301 disturbance layers noticed over Madras-Bangalore, 33 showed a temperature reversal of 1·5° or more. Of these, 27 were inversions of 1·5° to 2·9°, and 6 only showed a rise of temperature between 3° and 5·9°C. The distribution of these 33 inversions at different heights and in different months are shown in *Table X* (*b*).

TABLE X (*b*)

Inversions of 1·5°C or more (Madras-Bangalore).

Months \ Height (gkm)	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
January	1	3	1	0	0	0	1	0	0
February	0	2	1	0	0	1	0	0	0
March	0	0	1	1	2	0	0	0	0
April . .	0	0	0	0	0	0	0	0	0
May	0	1	0	1	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0
August	0	0	0	1	1	1	0	1	0
September	0	1	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0
November	1	2	0	0	0	0	0	0	0
December	3	5	1	0	0	0	0	0	0
Year	5	14	4	3	3	2	1	1	0

It is seen that the majority of such marked inversions occurred in the winter months at heights usually below 3 gkm. Low clouds of cumulus or stratocumulus type were present in most cases during November and December, but the inversions of January and February were often associated with practically clear skies. An examination of the normal upper air charts shows that during November and December, the air over Madras and Bangalore up to a height of about 2 gkm above sea level come from the south Bay of Bengal and is moist, while the air above which is a part of the anticyclonic circulation with origin in northern India is usually dry. A sharp discontinuity of moisture thus exists at the boundary of the two airmasses which probably accounts for the more or less permanent inversions or isothermal layers at heights of the order of 2 gkm over Madras and Bangalore during these months. The height-humidity curves relating to ascents in these months also show in each case a large and sudden fall in relative humidity near about the level of the disturbance layer, the humidity transition being found to occur at a lower height than usual when the base of the inversion or isothermal layer is low, and *vice versa*. Relative humidity values in the lower layers are usually of the order of 80 to 60%, and change to 40 to 20% at a small height above the inversion layer. The comparison of S. P. Ts. at height slightly above and below the inversions further shows that the air above has a lower S. P. T. than the air below, and this would seem to suggest that, unlikely the disturbance layers at the corresponding levels over Poona which appear to develop in a more or less homogeneous air mass, those of the south Peninsula originate at the boundary of two air masses, *viz.*, oceanic air below and land air above. It is, however, probable that the dry air aloft, which has the same source as the Poona air, undergoes anticyclonic subsidence and further accentuates the inversion which forms originally at the top of the moist air layer. Such a subsidence of the land air reaching the south Peninsula from northern India has been postulated by Malurkar* in explaining the extreme dryness observed at Kodaikanal during the winter months.

The inversions at the lowest levels (1 to 3 gkm) in January and February also appear to have a similar origin. Often in these months, however, the lower easterly air is a continuation of the land air from northern India with a short sea travel over the west Bay of Bengal and is not in consequence as moist as the air at the corresponding levels in November and December. The moisture discontinuity between the lower air layer and the air above is, therefore, not sufficiently well marked always to give rise to the inversion, which explains the smaller frequencies of disturbance layers in January and February compared to those in the preceding two months. Also the comparative dryness of the lower air causes the condensation level to be raised, particularly in the afternoon, to a height greater than that of the inversion layer, and this probably accounts for the frequent absence of low clouds at the time of sounding balloon ascents on days of marked inversions in January and February. The inversions at heights of 3 to 4 gkm in January to April do not in most cases show any marked humidity discontinuity, and humidity values below the inversion levels are usually low, of the order of 50 to 40%. It would appear that these inversions generally develop in one and the same air mass and are caused mainly by the descent of air in the anticyclone, the core of which moves down to the southernmost latitudes during these months. With the advance of the season, the anticyclonic descent of the air to lower heights is checked by the increasing convective activity in the lower layers and the disturbance layers tend to form at higher and higher levels. In the summer months, convection and resultant turbulent mixing during day are very marked and extend to a considerable height, often reaching the level of medium clouds, and appear to play a prominent part in the formation of inversions at heights of 4 to 6 gkm. It is however not possible always to distinguish the

* S. L. Malurkar,—Ind. Met. Dep., Sci. Notes, 4, No. 43.

turbulence inversions of this kind from those caused by radiation along the surface of moisture discontinuity, for the level which marks the limit of turbulence very often develops into a level of moisture discontinuity also and coincide at times with the top of a cloud layer. The more marked amongst the inversions in the southwest monsoon season are associated with clouds at about the same level and may be considered to be typical cloud inversions. The inversions at heights of 4 to 7 gkm during this season probably originate at the boundary of the westerlies at lower levels and the easterly circulation above. The mean height at which such a transition of wind occurs at the latitude of Madras and Bangalore varies from about 6 km in July to about 4km in September (*vide Figs. 6* and *7* in *Plate II* of the Memoir* on the "General circulation of the atmosphere over India and its neighbourhood".)

Disturbance layers with vertical extent of 0·3 gkm or more.—In all, there were 83 cases out of a total of 301 in which the disturbance layers over Madras-Bengalore had a depth of 0·3 gkm or more. The distribution of these diturbance layers at various heights in different months is shown in *Table XI (b)*. It is seen from the table that these disturbance layers of comparatively large vertical extent are most frequent during the months December to February. The vertical course of such disturbances shows, on the annual mean, a maximum at 2-3 gkm level and decreasing frequency at higher levels—the same features as have been observed over the north Peninsula.

TABLE XI (*b*).

Disturbance layers of depth 0·3 gkm or more (Madras-Bangalore).

Height (gkm) / Months.	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
January	2	6	1	2	1	1	0	0	0
February	0	4	5	3	2	1	0	1	0
March	0	0	2	0	1	0	0	0	0
April	0	0	1	2	2	0	1	0	0
May	0	0	0	0	0	1	0	1	0
June	0	1	0	0	0	0	0	0	0
July	0	0	0	1	1	1	1	0	0
August	2	0	0	0	1	0	0	0	0
September	0	0	2	2	2	1	0	0	0
October	0	1	0	0	0	0	0	0	0
November	3	1	0	0	1	0	0	1	0
December	4	7	2	1	0	3	0	0	0
Year	11	20	13	11	11	8	2	3	0

*K. R. Ramanathan and K. P. Ramakrishnan,—Mem. Ind. Met. Dep. 26, Pt. 10.

Influence of disturbance layers on the mean lapse-rates of temperature over the south Peninsula.—*Table XII* (*b*) below gives the calculated values of what the mean temperature gradient would be between successive kilometre levels over Madras and Bangalore during the months December, March and July, if no inversion or isothermal layer was present, and also the difference between this calculated gradient and the real mean gradient at each level.

TABLE XII (*b*).

Months.	Height (gkm)	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
December	(A) Mean temperature gradient (°C/km) if no inversion or isothermal layer was present.	10·2	7·8	6·7	6·2	7·3	7·2	7·2	7·9	8·2
	(B) Difference between (A) and the actual mean gradient.	2·9	4·1	0·9	0·2	0·3	0·4	0·2	0·0	0·0
March	(A) . .	9·3	9·0	6·7	6·2	5·6	6·5	7·5	8·4	7·9
	(B)	0·1	0·4	0·8	0·6	0·4	0·3	0·1	0·0	0·0
July	(A)	8·3	6·6	6·8	5·6	7·0	5·5	7·4	7·5	8·5
	(B)	0·3	0·1	0·3	0·6	0·5	0·5	0·4	0·0	0·0

It is seen that the influence of the disturbance layers on the mean temperature gradient is most marked in December at 2-3 gkm level where the difference between the inversionless and the real mean temperature gradient is as much as 4·1°C. The maximum effect of these disturbances occurs at 3-4 gkm in March and at 4-5 gkm in July. *Fig.* 2 gives the mean height-temperature curves for these three months, with the effect of the disturbance layers indicated on them.

Heights of sudden transition of wind and their association with layers of temperature disturbances.—In order to see how far the levels of sudden transitions of wind are associated with inversions and isothermal layers in the free atmosphere, the afternoon pilot balloon trajectories of Poona for the months of March and November, 1938 and of Hyderabad for July 1938 were examined, and the heights at which marked changes occurred in the wind direction or velocity or both were tabulated. *Table XIV* below gives the percentage frequencies of occasions on which such transitions occurred at various heights during these months.

TABLE XIV.

Percentage frequencies of wind transition at various levels over Poona-Hyderabad.

Months. / Height (gkm)	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10
March	29	39	26	33	14	25	5	18	0
July	29	25	72	33	50	0	..	..	..
November	40	80	42	21	18	16	11	6	17

A comparison of the frequency values as given in the above table with those for the corresponding months in *Table II* (*a*) shows a fair agreement in the nature of the distribution of the two frequencies with height. The individual frequency values in the two tables are however not quite the same, and it is in fact seen that the frequencies of wind transitions especially at lower levels are generally greater than those of the temperature disturbance layers. This is due probably to the fact that the wind and temperature data do not relate to the same dates and hours of observations and, also, that such transitions of winds need not necessarily be associated with inversions or isothermal layers, but may also be caused by marked changes in the vertical temperature gradients. Again, *Table XV* below gives the heights of base of inversions of 1·5°C or more over Madras and Bangalore and also the heights of the nearest levels of wind transitions on those days, as gathered from pilot balloon trajectories in the afternoon. On days on which no pilot balloon ascent was made in the afternoon, or when the ascent in the afternoon failed to reach the height of the inversion layer, the heights of wind transition as given in column 3 have been based on pilot balloon data in the morning.

TABLE XV.

Date.	Height of base of inversion (km).	Height of wind transition (km).	Date.	Height of base of inversion (km).	Height of wind transition (km).
24-5-33	2·13	No sudden transition of wind.			
17-8-33	5·70	Do.	17-3-38	5·48	5·3 (*m*)
21-9-33	2·32	2·5	4-5-38	4·53	No sudden transition of wind.
2-12-37	3·05	3·1 (*m*)	14-1-39	2·52	2·3
16-12-37	1·99	1·9	3-2-39	2·73	1·9
16-1-38	2·72	2·7 (*m*)	8-2-39	2·1	2·3
22-1-38	2·31	1·7 (*m*)	4-12-39	1·68	1·5
25-2-38	3·35	3·2 (*m*)	15-12-39	1·75	1·9
28-2-38	2·7	3·0 (*m*)	20-12-39	2·25	2·1
7-3-38	3·42	3·0 (*m*)	21-12-39	2·16	2·2
15-3-38	4·0	4·0	22-12-39	2·1	2·5
15-3-38	5·1	4·8 (*m*)	29-12-39	2·2	2·0

(*m*) denotes heights based on morning pilot balloon trajectories.

It is seen from the above table that the heights at which marked inversions occur are characterised, as a rule, by abrupt transitions of wind, although this does not mean that the converse is also true.

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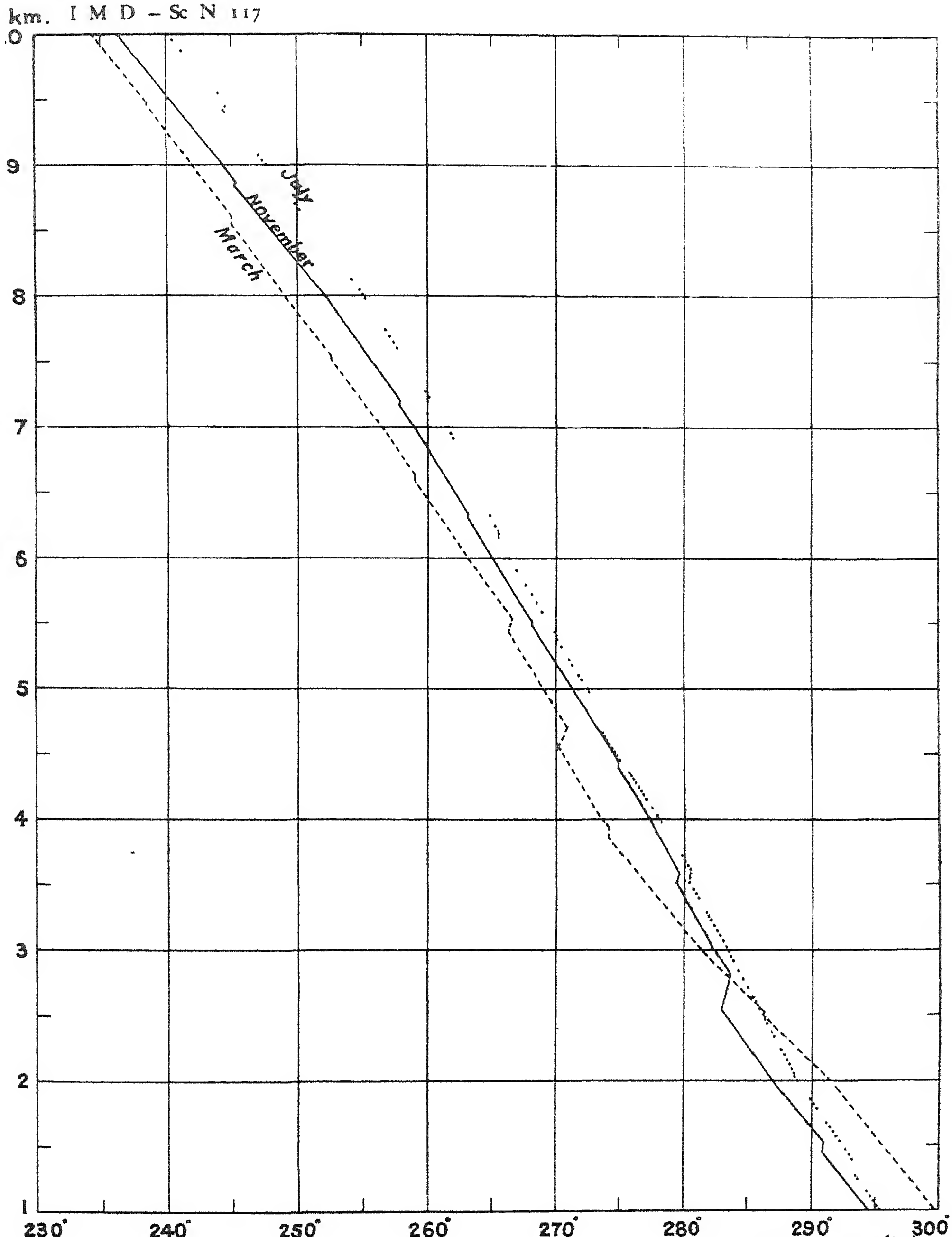

FIG. 1 HEIGHT-TEMPERATURE CURVES FOR THREE REPRESENTATIVE MONTHS AT POONA-HYDERABAD, SHOWING THE MEAN POSITIONS AND DEPTH OF DISTURBANCE LAYERS

G P Z P POONA, 1941

I. M D – Sc N. 117

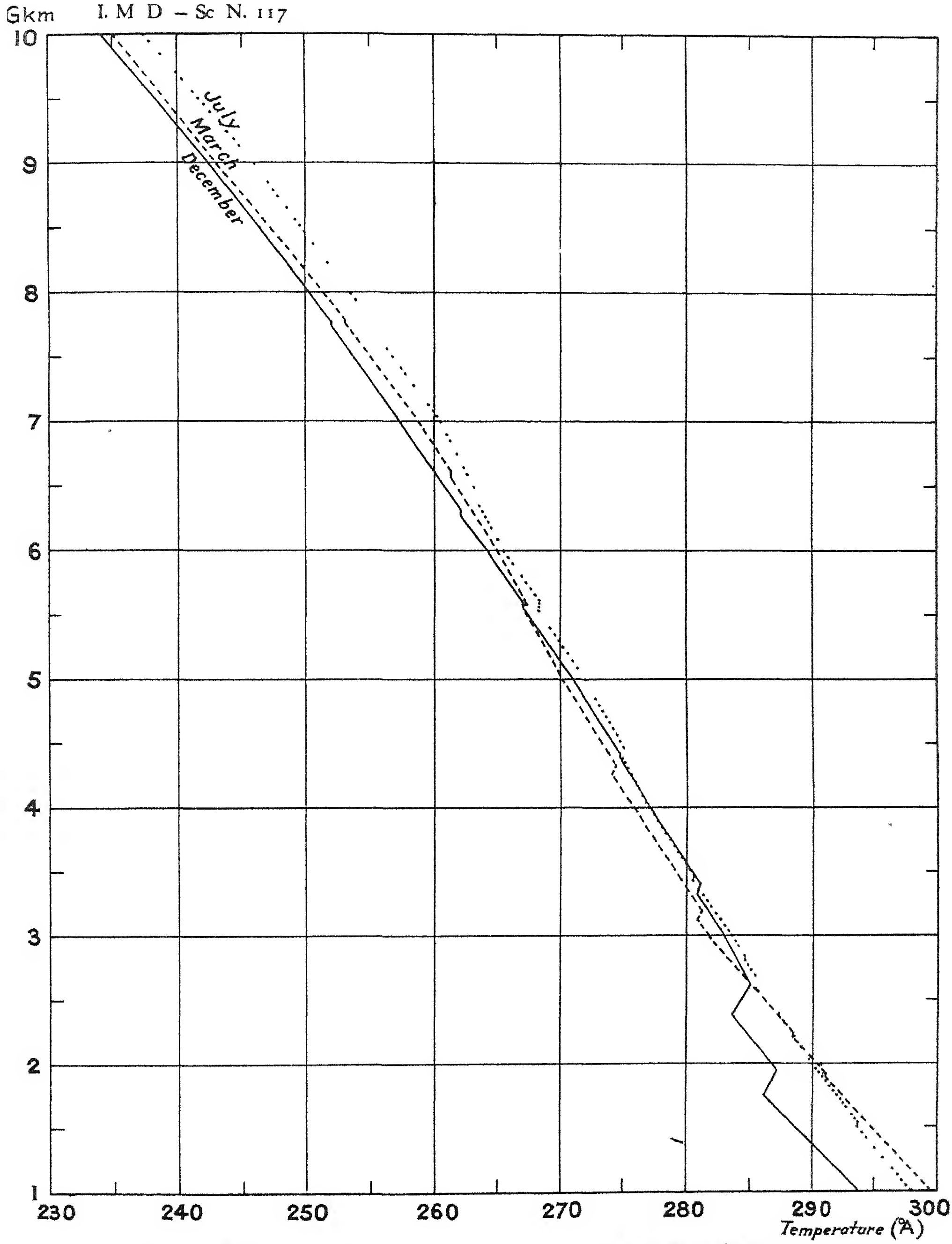

FIG. 2 HEIGHT–TEMPERATURE CURVES FOR THREE REPRESENTATIVE MONTHS AT MADRAS – BANGALORE, SHOWING THE MEAN POSITIONS AND DEPTH OF DISTURBANCE LAYERS

G P Z P POONA, 1941

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ON MICROSEISMS RECORDED IN INDIA AND CEYLON

BY

S. M. MUKHERJEE

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On Microseisms Recorded in India and Ceylon

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Abstract.—Microseisms due to a few selected storms in the Bay of Bengal and in the Arabian sea, recorded by the Milne-Shaw seismographs in India and Ceylon were studied. It is found that the period of microseisms increases as the distance of the source of the microseismic disturbance The mean variation is about half a second for a distance of nearly 2,000 km —the maximum distance available in this study. The differences of the means between the different stations are found to be statistically significant and the standard deviations are $\pm 0 \cdot 2$ to $\pm 0 \cdot 3$ sec The variation in India satisfies the relation $T^2 = T^2_0 + K\triangle$ (Km) where T_0 is the initial period and T the recorded period at the distance $\triangle$, if the value of the constant K is taken as 1/400. This suggests a value of about $5/12 \times 10^9$ poises for the internal friction of the surface layers of the earth in India.

The period is smaller in hot months than in winter. The ratio of the amplitudes in the N-S and E-W components is unity irrespective of the azimuth of the source of the disturbance from the recording station but confirmation of this aspect requires further study.

The data from the seismograms at Ceylon do not fall in line with those of the Indian observatories.

Introduction.

In studying the seismograms at Bombay the author often noticed that the periods of microseisms due to storms originating in the neighbourhood of Bombay in the Arabian Sea were generally smaller than those due to storms further away in the Arabian Sea or in the Bay of Bengal. On the basis of these casual observations, the former periods were found to be generally near about 4 seconds while the latter, about 5 seconds or more.

Whenever characteristic microseisms are recorded at Bombay, reports relating to their nature and intensity are sent to the Headquarters Office of the India Meteorological Department, Poona, to assist in forecasting the weather. When the periods belonged to either of the above categories, we sometimes used to add in our reports if the centre of the microseismic disturbance was near or away from Bombay.

Do the periods vary systematically as the distance of the disturbance from the recording station as the seismic surface waves do ? (1) If so, what is the amount of variation ? Could the recorded periods at the different Indian stations be utilised to give an idea of the distance of the storm-centre from the stations ? The present investigation was undertaken to examine these points.

As a result of subsequent search in the available literature on the subject of the variation of the period of microseisms with distance of the source of disturbance the following information could be culled. Gutenberg (2) in summarising the results of observations made by himself and his predecessors in regard to Europe, says, " High surf against the coast of Norway is always recorded even as far as Irkutsk in the heart of Asia. In this case the whole northern half of Europe and western half of Asia show vibrations of nearly the same period ranging in general from 6 to 8 seconds.. ..... ". In his studies on " Microseisms in N. America " (2) he, however, finds that the periods of microseisms in N. America vary as the distance of the source of the disturbance. He gives an empirical formula representing the variation of the period with distance. From this equation he calculates the variation of periods (for $\triangle = 0$ to $\triangle = 5000$ km) corresponding to the values of the initial periods 0·1, 1and 4·1 seconds and remarks that the order of these values agrees very well with observations. Elsewhere (3) also he comes nearly to the same conclusion on the results of subsequent observations in America but neither the observational data nor curves showing the variations actually observed appear to be available in the papers under reference. Lee has later made a world wide survey of microseisms (4) and on the basis of his findings concludes as follows, (5) " .. .. during these 'microseismic storms ' the disturbances are widespread, *vibrations of nearly the same period are recorded*, for instance, throughout the whole of northern Europe and western Siberia *or over the greater part of North America*.. .. .. " J. Emilio Ramirez (6) on the other hand says that " the period of microseisms seems to be a function of the distance between the station and the source of microseisms ", but no observational evidence in support of the conclusion is given. Microseisms recorded in India have been studied by Dr. Banerji (7) but this particular aspect of the subject, namely, the observed variation of the period with distance of the source of disturbance, has not been discussed. It is not known to the present author if the results of systematic variation of the periods of microseisms with distance have been published elsewhere.

Selection of the Storms.—It is necessary to make a selection of the storms giving rise to the microseisms which are to be studied. The microseisms should be well recorded and their amplitudes as large as possible in the different stations, the records of which are to be used. In that case, greatest ease in reading and accuracy of the results of measurements can be expected. The disturbance under study should be due to a single source and, it should be carefully noted by a survey of the weather maps that there is no other source of storm or depression in the neighbouring seas. This will eliminate objection relating to superposition of different periods from the different storm centres. Care, as far as practicable, to satisfy these conditions, has been taken in the present study.

The storms selected were those of 1940 Oct. 16, 1937 Oct. 14 and 1933 Dec. 15-16. The first storm occurred in the Arabian Sea and crossed the coast near Bombay on the morning of the 16th. It was the severest storm ever recorded in living memory at Bombay. The Milne-Shaw seismographs failed to record for some hours due to failure of electric supply of the city. From 07 to 08 hours (I.S.T.) in the morning the storm appears to have been the severest. Calcutta was the farthest station recording the storm. The vibrations were well recorded at all the stations. The second storm was in the Bay of Bengal and its centre, within 200 miles of Calcutta on the 14th.

This was also a severe storm and the microseismic movements as recorded at Calcutta were exceptionally large. Bombay and Kodaikanal were the farthest stations registering this storm. The movements due to this storm were quite prominently recorded at Bombay. Records at the other Stations were also clear. The storm of 1933 Dec. 15-16 was also a severe one and originated in the Bay of Bengal. Kodaikanal was the station nearest to the centre of this disturbance and Agra, the farthest. Bombay was about 700 miles away but the microseisms due to it were quite clearly recorded. It may be mentioned that this storm originated in winter while the other two in a post-monsoon and hot month. From these 3 storms, data at the different distances between 50 and 1100 miles are available. The tracks of these storms and the portions of the microseisms recorded at the selected stations are reproduced in *Fig. 1*, (a) and (b) respectively. In the Omori-Ewing records of the microseisms due to the 1940 Oct. storm at Bombay microseismic movements of nearly 4 seconds period are clearly seen superposed on motions due to instrumental periods of 25-30 seconds. It is to be remarked that the free periods of the pendulum of the Milne-Shaw instruments the records from which have been used, are between 10 and 12 seconds and hence the microseismic periods of 4-5 seconds could not have been influenced by the free periods of the pendulum.

Records Used.—The photographic records of the Milne-Shaw seismographs at Bombay, Calcutta, Agra, Kodaikanal. Hyderabad and Colombo were obtained for tabulation. Bombay and Hyderabad had both E & N components, Calcutta N and the rest E components. The static magnifications of the instruments were 250 or 350 and the free periods of the pendulums, as already stated, were 10 or 12 seconds. It was therefore possible to utilise the photographic records from the E component of the Milne-Shaw seismographs at all the stations except calcutta where the records from the N component were used. Objections due to possible uncertainties in the results due to difference in the type of recording and the instruments do not therefore arise.

Tabulation.—*Periods.*—In the case of 1940, October storm, the method of tabulation was as follows. It was assumed that the microseismic waves travelled with an average speed of about 2·67 km/sec. (6). Each individual minute interval where the period had to be read, was measured and the value of the time scale in that particular interval determined. Where the time scale was appreciably out of the usual value, that is 8 mm/sec., no reading was taken. A magnifying lens and a glass scale graduated in half mm. were used. In an interval of half an hour centred at the full hour at Bombay, 4 minutes after the hour at Hyderabad, 7 minutes at Kodaikanal and Agra and 10 minutes at Calcutta and Colombo, some 10 groups of sinusoidal waves having amplitudes generally larger than the remaining groups of waves in that interval were selected for tabulation. Generally the mean period from 4 to 6 or more waves in each individual reading was taken. It was later found that so much elaboration was not necessary to bring out the general features aimed at. As such, in the other two cases an interval of 20 minutes was chosen after the full hour at each station and the average period of the first ten groups of regular waves was taken. The amplitudes of these waves were not necessarily larger than those of others in the particular interval. The hours were I.S.T. The periods are given in seconds and tenths.

Amplitudes.—Amplitudes were measured only from the Bombay seismograms. The amplitudes of the maximum movements occurring in each of the 10 minute intervals after the full hour were measured. Half of a to and fro movement (crest to trough) was the amplitude. The breadth of the trace was taken into consideration in each measurement. The mean of these ten readings represents the mean hori-

zontal displacement of the earth in microns (μ) in the component in question. Finally the value $\frac{1}{2}\left(\frac{\mu_N}{\mu_E}+\frac{\mu_E}{\mu_N}\right)$ was taken for the ratio of the amplitudes.

Readings were taken from the portions of records where the microseismic movements were the most pronounced. In respect of the 1933 December storm, readings at intervals of 3 hours commencing from 1 hour on the 15th and ending at 4 hours on the 16th were taken. Besides these, values at a few more hours are also available. The hourly means for all the stations except Colombo where the recording was defective, as well as the averages of all the hourly readings are given in *Table I*. In the case of the 1937 and 1940 October storms, readings for all the available hours (0 to 13) for the former and 1 to 15 hours for the latter and the average hourly values for all the stations including Colombo are given in the same table with the approximate distances of the mean positions of the centres of the storms from the recording stations as measured from the relevant weather maps. At Bombay, readings from both the components (N, E) in respect of the 1933 December and 1940 October storms are given. In the case of the 1937 October storm, only the E component was tabulated.

Discussion of Results.—*Mean variation.*—It will be noticed that while the average values of the periods in both the components in respect of the 1933, December storm at Bombay are practically the same, in the 1940 October storm the period from the E component is greater by 0·2 second than that from the N component. This point requires further examination.

It seems clear that the average period of the microseisms increases as the distance of the source of the microseismic disturbance, the mean variation being about half a second over a distance near about 2000 km. Curves showing the variation of the periods with distance in respect of the three storms are reproduced in *Fig. 2* In this figure are also given the theoretical curves of variation of the seismic surface waves according to Sezawa's formula partially verified by Gutenberg's observations and the theoretical curve of variation of the microseismic periods with distance according to the formula $T^2=T^2_0+0{\cdot}01\triangle$ (km) due to Gutenberg. Here T=the observed period, T_0=the initial period and $\triangle$ = the distance of observation.

The observations in India satisfy Gutenberg's theoretical relation if the value of the constant is made one-fourth of that adopted by Gutenberg. It would be noted that this would be 1/10th of the value of the constant adopted in Sezawa's formula of variation of seismic surface waves (1). This would suggest a value of $5/12\times10^9$ poises (8) for the internal friction of the surface layers of the earth in India, if we assume that the velocity of the waves does not deviate much from 3 km/sec. More observations are however necessary for such studies.

It is noteworthy that the curve for the 1933 December storm is much above those for the October storms, the latter being close to each other. They corroborate the general observations of other investigators made in India and elsewhere that the periods of microseisms during winter are larger than those in the summer months.

It will be noticed that the values of the recorded periods at Colombo do not fall in line with the observations in India and are generally smaller than the values observed at the corresponding distances in India. The average values in respect of the two October storms, however, differ from each other by as much as half a second though the distances of the centres of these disturbances from Colombo differed only by about 300 km. These points deserve further examination.

Hourly Variations.—The hourly average values of the periods at Calcutta, Agra, Kodaikanal and Bombay for the three storms are plotted in *Fig. 3.* The maximum range of oscillation of the period at any station in the 1937 storm is about 0·3 second while that in the other two is double this amount. There is no close

correspondence in the hour to hour variation at the different stations and sometimes the variations are in opposite directions. Following are the general features noticeable. Regarding the 1933 December storm, the periods at all the stations except Agra are smaller than the average between 1 and 10 hours, greater up to 22 hours and fall below it thereafter. At Agra, though the period falls systematically from the beginning till the end, the general trend of the curve is opposite to that of the other stations. The readings from both the N & E components at Bombay are plotted. These curves go almost hand in hand. In respect of the 1937 storm, there are both similar and opposing tendencies of the curves but they do not much deviate from the mean The curves of the 1940 October storm, on the whole, exhibit tendency of parallel variation at the different stations. The conspicuous features are the low values between 8-9 and 15 hours and high values in the earlier part of the disturbance. It may be seen that either from the analysis of the mean values or of the individual readings, the frequency distribution of which has been discussed later, it does not appear that the microseismic movements in India are more irregular at the stations nearer the centre of the disturbance than those at the distant ones. The standard deviations of the periods with regard to these storms at the near and distant stations do not show any appreciable divergence from one another and are between $\pm 0 \cdot 2$ and $\pm 0 \cdot 3$ second.

Frequency Distribution.—The frequency of occurrence of the periods as percentages of the total number of readings, in groups of two consecutive values at an interval of $0 \cdot 2$ second for Bombay, Agra, Calcutta and Kodaikanal, is exhibited diagramatically in *Fig. 4*. All the readings were used. The notable features in respect of all the storms are that the distribution is normal with a more or less prominent hump round about the mean value of the period, the bodily shifts of the curves from one another are clear and according to expectation. In respect of the 1940 storm, there are two prominent humps in each of the curves at Bombay and Calcutta at an interval of $0 \cdot 4$ second in each. The peaks are of nearly the same height. The displacement of the first and the second peak at Calcutta from the corresponding peaks at Bombay is $0 \cdot 8$ second. In the curves for Agra and Kodaikanal (not shown), there is rather a long tail of larger periods. In the curves for Agra and Calcutta (not shown) in respect of the 1933 December storm, there appear to be two concentrations of periods differing from each other by $0 \cdot 4$ second. For this storm distribution of the readings from both the N and E component at Bombay appears to be similar. The readings from the E component only are plotted.

Test of Significance.—Variation of the period with distance in India is very small and no claim can be made at this stage on the accuracy of the absolute magnitude of the variation obtained. Nevertheless from the preceding discussion it would appear to be clear that the period of microseisms at a station very near the source of the disturbance is smaller than that at a distant station and, roughly, the variation is of the order of about half a second over a distance of near about 2,000 kms. The observed differences of average periods between the stations at the different distances are often much smaller than this amount. It therefore remains to be seen whether they are statistically significant. To examine this point we apply Fisher's 't' test [9]. We use the following expression which is applicable to test the significance of the difference of the means of two small samples :—

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\dfrac{S_1 (X_1 - \bar{x}_1)^2 + S_2 (X_2 - \bar{x}_2)^2}{(N_1 - 1) + (N_2 - 1)}} \times \sqrt{\dfrac{1}{N_1} + \dfrac{1}{N_2}}}$$

where X_1 and X_2 are the individuals of the two samples,

$\overline{X}_1$ and $\overline{X}_2$ are the two means,

N_1 and N_2 the total numbers,

and S_1 and S_2 are the summations over the samples.

In our case, the number of readings used in each station is 100 or more and hence we use N_1 and N_2 in place of N_1-1 and N_2-1 in the above expression. We calculate the values of "t" in respect of the differences of the means between the pairs of stations: Kodaikanal and Bombay, Kodaikanal and Agra and Bombay and Agra in respect of the 1933 December storm, between Calcutta and Bombay, Calcutta and Agra, and Bombay and Agra in respect of 1937 October storm and between Calcutta and Bombay, Calcutta and Agra, and Bombay and Agra in regard to the 1940 October storm. The values of "t" range between 3·4 and 15·2 and therefore indicate that the differences of the average periods are above one per cent level of significance.

Amplitudes.—The ratios of the tabulated amplitudes of the two horizontal components at Bombay in respect of the 1933 December and 1940 October storms are given in *Table 2*. The values for one hour in respect of the Malabar storm of May 26, 1941 which occurred due south of Bombay, are also given in this table. These values are unity and are independent of the azimuth of the source of the disturbance from the recording station. These results agree with the observations of Gutenberg and Lee referred to before.

My best thanks are due to Dr. S. R. Savur, Director, Colaba Observatory for kindly making all the facilities available for the work and to Dr. K. R. Ramanathan for his kind interest and some suggestions in the work.

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Table 1.

Mean periods in Secs.

Station.	(Km.)	Component.	Hrs. I. S. T. 1	4	7	9	10	11	12	13	14	16	19	22	1	4	Mean.
1933 Dec. 15-16—																	
Kodaikanal	320	E	4·8	4·4	4·4	4·6	4·5	..	..	Congestion of record.	4·9	4·9	4·7	4·6	4·5	4·5	4·62
Hyderabad	680	N	4·9	4·8	4·75	4·8	5·0	..	..	5·0	..	4·7	4·9	5·0	4·9	4·6	4·85
Bombay	1,170	N	5·0	4·8	4·8	4·75	4·7	4·8	4·9	4·8	4·9	5·0	..	4·9	4·6	4·6	4·81
		E	4·8	4·8	4·8	4·8	4·9	..	..	4·9	..	4·9	4·8	4·7	4·6	4·6	4·79
Calcutta	1,500	N	4·9	4·9	5·0	4·8	4·95	..	..	5·1	..	Congestion in record.	5·1	5·1	4·6	5·0	4·95
Agra	1,770	E	5·2	5·1	5·0	5·1	5·0	..	..	4·8	..	4·9	4·8	4·75	4·9	4·6	4·93
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	Mean.
1937 Oct. 14—																	
Calcutta	180	N	4·2	4·1	4·2	4·2	4·1	4·1	4·1	4·1	4 2	4·2	4·2	4·2	4·3	4·1	4·16
Hyderabad	1,290	N	Small and hence doubtful for correct reading.					4·6	4·7	4·6	..	4·5	4·5	4·3	4·2	4·5	4·5
Agra	1,320	E	4·4	4·5	4·5	4·4	4·5	4·4	Record lost.		4·7	4·6	4·7	4·7	Light blurred.		4·5
Bombay	1,800	E	4·5	4·5	4·6	4·6	4·6	4·6	4·7	4·8	4·8	4·55	4·6	4·6	4·5	4·4	4·6
Kodaikanal	1,830	E	Small and hence doubtful for correct reading.					4·5	4·6	4·6	4·6	4·8	4·6	4·9	4·6	4·7	4·65
Colombo	1,960	E	3·8	..	3·8	..	3·9	..	..	4·0	4·0	4·1	4·0	..	..	..	3·9

TABLE 1—*contd.*

Hrs. I. S. T.

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Mean.
1940 Oct. 16—																		
Bombay	80	E	4·4	4·2	4·15	4·2	4·3	4·2	..	..	4·4	4·1	4·2	4·1	3·9	4·0	4·1	4·17
		N	3·9	4·0	3·9	3·7	3·9	3·9	(Record		lost)			(Congestion of lines)				3·9
Hyderabad ..	640	E	4·5	4·5	4·5	4·4	4·9	4·1	4·7	.	4·3	4·3	4·4	4·2	4·4	..	..	4·4
Agra	1,110	E	4·4	4·6	4·3	4·55	4·7	4·3	4·5	4·3	4·6	4·3	4·3	4·2	4·3	4·35	4·6	4·4
Kodaikanal ..	1,110	E	..	4·7	..	4·5	4·8	..	4·5	4·6	4·3	4·4	4·4	4·6	4·4	4·7	4·8	4·6
Calcutta	1,720	N	5·0	4·9	5·1	4·9	5·0	4·9	4·7	4·9	4·5	4·5	4·4	4·5	4·5	4·6	5·0	4·76
Colombo	1,690	E	4·1	4·2	4·2	4·1	4·2	4·2	4·4	4·5	4·3	4·5	4·4	4·3	4·6	..	..	4·40

TABLE 2.

Amplitudes in μ.

1933 December 15-16.

Hrs. I. S. T.

Component	1	4	7	10	13	16	22	1	4	Mean.
N	0·52	0·68	0·92	1·08	1·48	1·56	0 80	0·80	0 76	
E	0·43	0·60	0·71	0·86	1·11	1·11	0·77	0·83	0·49	
(1) N/E	1·21	1·13	1·31	1·26	1·33	1·41	1·04	0·96	1 55	
(2) E/N	0·83	0·88	0·77	0·80	0·75	0·71	0·96	1·04	0·64	
Mean (1) & (2) ..	1·02	1·01	1·04	1·03	1·04	1·06	1·00	1·00	1·09	1·03

1940 October 16.

Hrs. I.S.T.

Component.	0	1	2	3	4	5	6	Mean.
N	2·46	3·24	3·40	..	4·22	4·34	4·78	
E	3·33	4·01	4·24	..	5·24	5·31	7·73	
(1) E/N	1·35	1·24	1·25	..	1·24	1·22	1·62	
(2) N/E	0·74	0·81	0·80	..	0·80	0·82	0·62	
Mean (1) & (2) ..	1·05	1·03	1·03	..	1·02	1·02	1·12	1·03

1941 May 22 (one hour only).

Component.	Mean of 10 readings (mm).
N	0·141
E	0·209
$\frac{1}{2}\left(\frac{\mu_N}{\mu_E}+\frac{\mu_E}{\mu_N}\right)$	1·00

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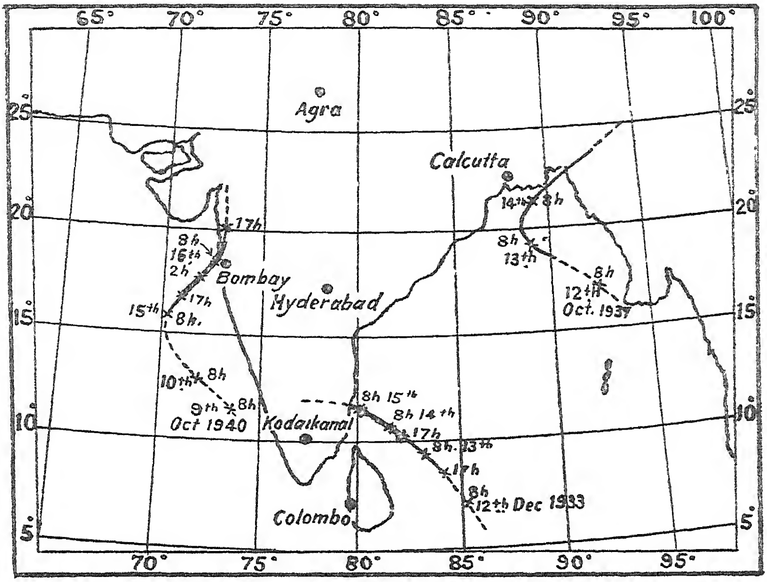


● .. .. SEISMOGRAPH STATIONS.
TRACKS OF SEVERE STORMS
" " STORMS.
" " DEPRESSIONS.

FIG. 1. (a).

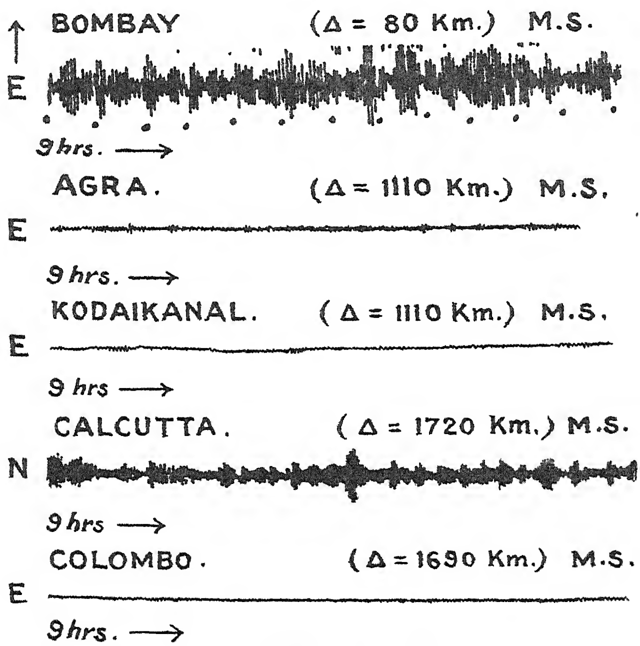
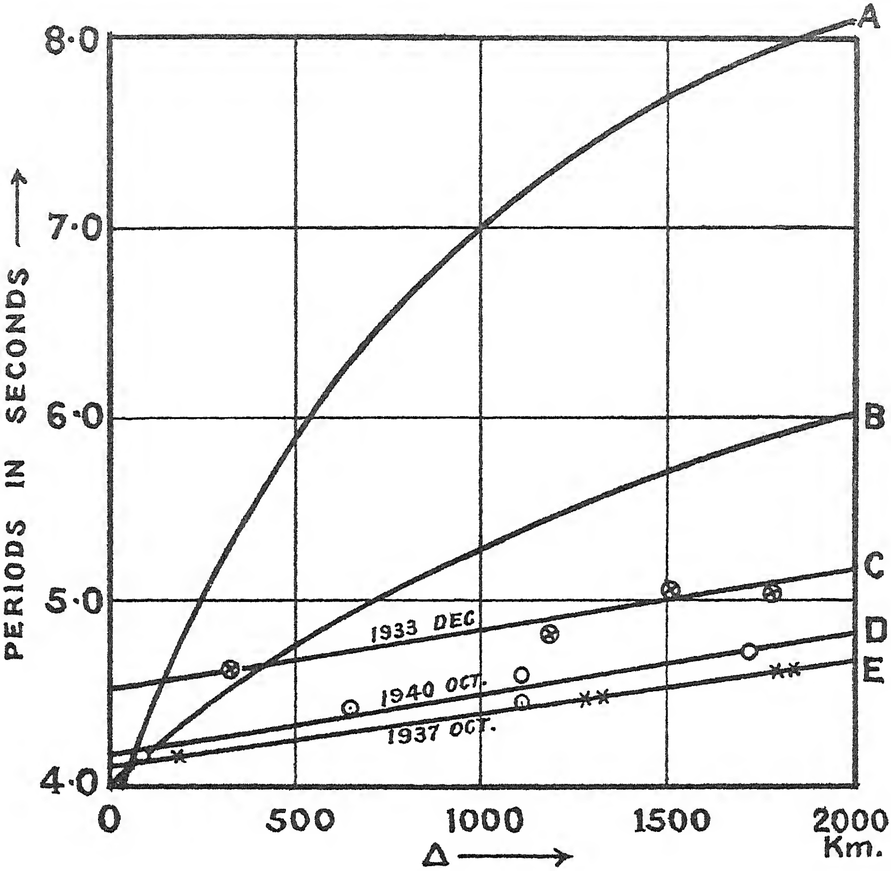


FIG. 1. (b).

MICROSEISMS DUE TO THE STORM OF 1940 OCTOBER, 16.

M. S. = Milne–Shaw Seismograms.

G.P.Z.P. POONA '46



A *Seismic surface waves — Theoretical.*

B *Microseismic waves — According to Gutenberg.*

C, *D*, *E* } *Microseismic—observed in India.*

FIG. 2. VARIATION OF PERIOD WITH DISTANCE

GPZ P POONA'46

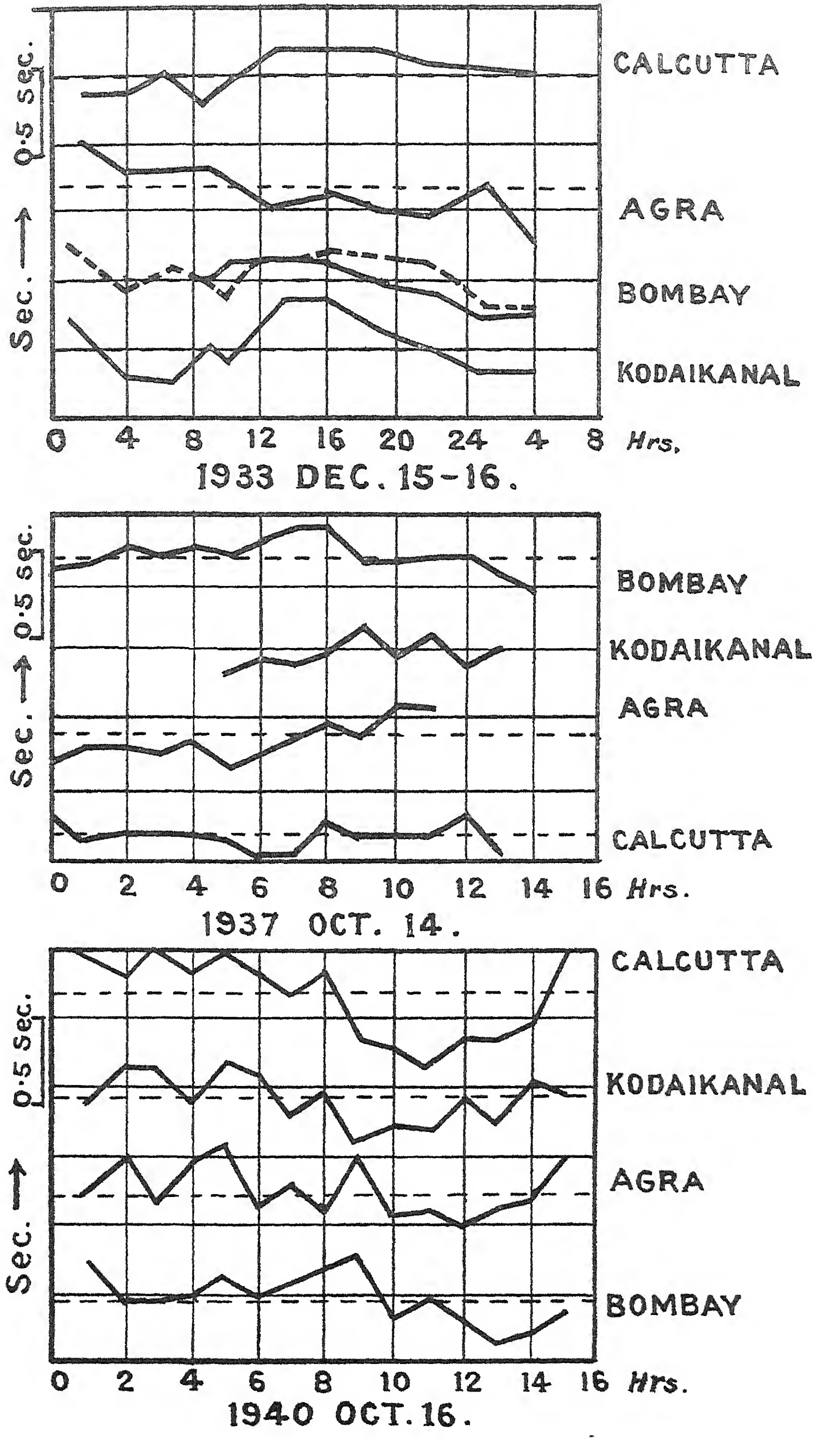


FIG. 3. HOURLY VARIATION OF PERIOD.

G P Z P POONA, 46

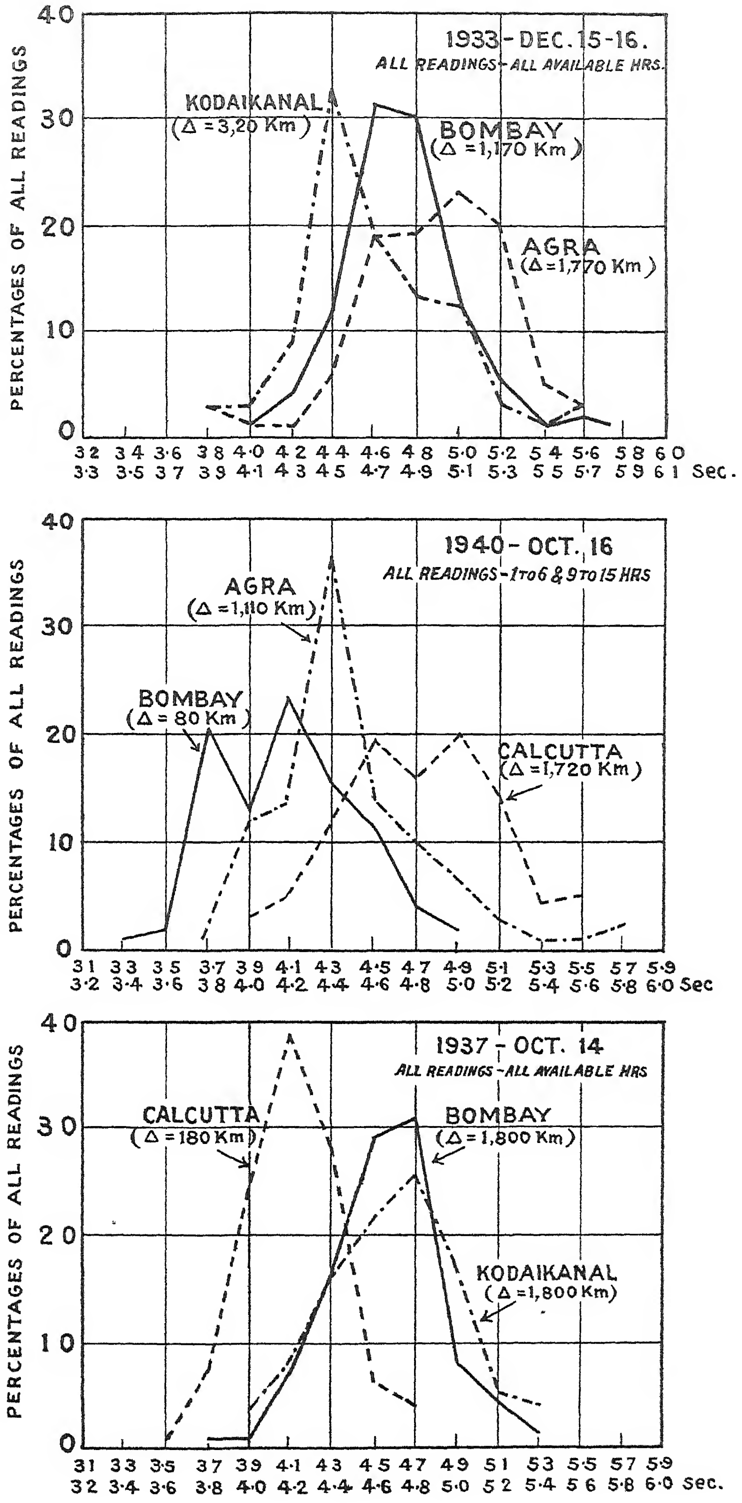


FIG 4 FREQUENCY DISTRIBUTION OF PERIOD.

DGO. 19 X 119
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INDIA METEOROLOGICAL DEPARTMENT

SCIENTIFIC NOTES

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THE SEA BREEZE AND DIURNAL VARIATION OF WINDS AT KARACHI

BY

S. N. RAY CHOUDHURI

(Received first on 21st December 1939 and in revised form on 5th January 1946)

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THE SEA BREEZE AND DIURNAL VARIATION OF WINDS AT KARACHI

BY

S. N. RAY CHOUDHURI.

(*Received on 21st December 1939 and in revised form on 5th January 1946.*)

Abstract.—During the winter months when the gradient wind at Karachi is generally of land origin afternoon sea breeze sets in on sunny days, unless the gradient wind is too strong. It is, however, observed that, although the sea breeze starts from a direction perpendicular to the coast line, it veers with the progress of the day Again, prior to the onset of the sea breeze and also on occasions when the sea breeze does not blow due to the gradient wind being strong, a veering or backing of the gradient wind is observed in the afternoon. This veering or backing is explained by the simple parallelogram law—being the result of compounding the gradient wind with the sea breeze. A comparison of the relative magnitudes of the gradient wind and sea breeze is made, leading to some criteria for judging from the morning conditions whether sea breeze is likely to blow in the afternoon.

Land and sea breezes are easy to detect when there are no strong or well defined pressure systems over the region considered. Although, however, the effect of land breeze is usually obliterated whenever there is an appreciable gradient wind (wind due to the general synoptic situation), the effect of sea breeze may be observed even when the gradient wind is appreciable. In Karachi, the gradient wind is usually weak and ill-defined in the transition months of October and March and purely local land and sea breezes are normally observed only in these months. In the months of May to September a fairly strong westerly breeze blows continuously in association with the seasonal low pressure area over northwest India. These westerlies, however, show a marked tendency to strengthen and back in the after-noon due to the effect of the sea breeze. In the months of November—February due to the establishment of seasonal high over northwest India, the winds over Karachi are generally of land origin and blow from a direction between northwest

and northeast. Local sea breeze, however, develops in these months in the afternoon unless the gradient land wind is too strong. The present note is a study of the effect of sea breeze on the gradient winds during these months and the conditions that are necessary for the onset of sea breeze in the afternoon over the land.

According to Jeffreys[1], the local winds of the type of land and sea breezes are essentially antitriptic. While Jeffreys' view is generally accepted, it has been pointed out by others (*vide* discussion on Jeffreys' paper, loc cit) that the acceptance of antitriptic character of sea breeze is likely to obscure the important fact that the sea breeze undergoes a veering with the progress of the day. At Karachi, the coast line runs approximately WNW to ESE. Accordingly, it has been observed that the sea breeze at Karachi first blows from a SSW to SW-ly direction—that is roughly along the sea-land pressure gradient. Even a casual examination of wind charts at Karachi, however, shows that by the late afternoon the SSW to SW-ly sea breeze invariably veers to W. *Table I* which reproduces the hourly wind direction at Drigh Road on sea breeze days in January 1937 clearly shows the veering of sea breeze with the progress of the day.

When there is no gradient wind the full effect of the local sea-land pressure gradient actuates the sea breeze normal to the coast line. With the prevalence of an appreciable gradient wind, the imposition of a local sea-land pressure gradient may be expected to make a gradient wind veer or back and give a resultant wind according to the parallelogram law. Further, if the strength of gradient wind is comparable in magnitude with the sea breeze component, a resultant wind is all that can be expected. The resultant of a gradient wind of land origin and sea breeze may sometimes give a wind which has partial sea travel but will not give a sea breeze of the antitriptic type, the arrival of which is characterised by a sudden wind shift, fall in temperature and rise in humidity as shown by Ramdas[2]. It is only when the sea breeze component far exceeds the gradient wind factor that a sea breeze of the antitriptic type will blow, obliterating the gradient wind factor.

Before passing on to a consideration of the relative magnitudes of the sea breeze and the gradient wind due to general synoptic situation, it may be pointed out that due to inherent lag between the development of a pressure gradient and its effect on the winds, the local sea-land pressure gradient may not be fully operative until a wind approximately from the direction of the pressure gradient begins to blow. This explains the frequently observed fact that the gradient wind usually veers or backs only upto E or NW before a sea breeze of the antitriptic type commences from SSW or SW. Several cases have, however, also been noticed when the gradient wind veered to S or backed to W before the onset of the antitriptic sea breeze. In such cases, as the winds would already have some sea travel prior to the onset of antitriptic sea breeze, the arrival of the latter will not be attended with the same contrast in temperature and humidity as when a purely land breeze is replaced by sea breeze. In cases when the gradient wind veers to S prior to the onset of sea breeze, it is also interesting to note that the surface winds make practically a complete cycle in the course of the day. The explanation for this is simple: suppose the gradient wind is from NE. As a result of the effect of sea breeze it veers and through the process of veering it becomes, say, S. Then let the sea breeze start from SSW. The sea breeze veers with the progress of the day (*vide* infra) and by late evening becomes, say, W. The sea breeze is then withdrawn and the wind comes back to its normal direction, *i.e.* NE, through N. Several examples of a complete cycle made in the course of the day through the process of veering will be found in *Table II*. It is obvious that a complete cycle cannot be made through the process of backing due to sea breeze effect and no case has so far been observed.

In order to have an idea of the magnitude of the sea breeze factor, the following equation* is useful :

$$\delta p = h.\frac{\delta T_m . g. p.}{RT^2}$$

where δp=the pressure difference over land and sea

δT_m =the mean temperature difference of the column of air of height h

h=the height at which the temperature equalises and consequently the pressure gradient vanishes.

R=gas constant

T=the mean absolute temperature

p=the mean barometric pressure

If the temperature lapse from the surface upto the height h is assumed to be uniform both over land and sea, δTm can be replaced by $\frac{\delta T}{2}$, where δT is the temperature difference at the surface. We then have,

$$\delta p = h.\frac{\delta T \, g.p.}{2RT^2}$$

where δT=the difference in surface temperature over land and sea.

We will further assume that up to the height h, dry adiabatic lapse rate of about 10°C per km prevails over land and that the usual lapse rate of about 6°C per km prevails over the sea when the maximum temperature contrast is attained. Then the height h upto which the temperature difference exists is $\frac{1000}{10-6} \times \delta T$ metres, or, $250 \delta T \times 10^2$cm.

Substituting for h in the above equation, we have

$$\delta p = \frac{250 \times 10^2 \times \delta T^2 \times g \times p.}{2 RT^2}$$

Now substituting the values of g, p, R and T ($g=981=10^3$ approx. $p=1000$ mb$=10^3 \times 10^3$ dynes approx. $R=2{\cdot}871 \times 10^6 = 2{\cdot}9 \times 10^6$ [redacted] approx. and $T=300°A$), expressing δT in °F instead of °C and evaluating, we have

$$\delta p = 14 \delta T^2 \text{ dynes approx.} \qquad \ldots\ldots\ldots\ldots \ (1)$$

Equation (1) gives the measure of pressure difference in terms of difference in temperature at the surface over land and sea.

We can now compare the pressure given by equation (1) with the pressure exerted by the gradient wind due to the general synoptic situation. Let $\triangle p$ be the pressure exerted by the gradient wind of velocity v, then

$$\triangle p = \tfrac{1}{2} \rho v^2 \text{ dynes.}$$

If V is expressed in metres per second, then the above equation becomes

$$\triangle p = \tfrac{1}{2} \times 10^4 \times \rho v^2 \text{ dynes.}$$

---

*The equation is easily derived from first principles. It has been put in a slightly different form in Humphrey's "Physics of the Air", namely,

$$h = -\frac{dB}{dT}.\frac{RT^2}{gB}$$

where dB and B have the same significance as δp and p respectively and dT corresponds δT_m in our equation.

Now substituting the value of ρ corresponding to temperature of 300° A and pressure of 1000 mb and evaluating, we have

$$p=5\cdot 8V^2 \text{ dynes.} \qquad \ldots\ldots(2)$$

where V is in m. p. s.

From equations (1) and (2) it will be seen that the gradient wind and the sea breeze are of equal magnitude when

$$14\delta T^2=5\cdot 8V^2$$

$$\text{or,} \quad \delta T^2=\cdot 41\, V^2$$

In order to have a sea breeze of the antitriptic type, it is obvious that δT^2 should be greater than $\cdot 41V^2$. In the particular case when the gradient land wind is from a direction exactly normal to the coast line, *i.e.* from NNE, the gradient wind will die down and a calm will result when $\delta T^2=\cdot 41V^2$ and a sea breeze is likely to blow when $\delta T^2>\cdot 41V^2$. If the gradient land wind is from a direction other than the normal to the coast line, the resultant of the gradient wind and the sea breeze can theoretically never be exactly from a direction from which the sea breeze comes. In practice, however, when the sea breeze factor exceeds a certain limit, the effect of the gradient wind is obliterated and an antitriptic sea breeze blows. If the gradient wind is say from NE or N, we will have a resultant wind from S or SW when the sea breeze factor is about twice the magnitude of the gradient wind. The resultant wind will in this case be very close to the direction of sea breeze and a sea breeze is likely to set in if the sea breeze factor is more than twice the magnitude of gradient wind. With a gradient wind from E or NW, the sea breeze factor has to be about 3 times the gradient wind factor to get a resultant wind from S or SW. The condition for the onset of antitriptic sea breeze are, therefore,

$\delta T^2>\cdot 41V^2$, when the gradient wind is NNE (*a*)
$\delta T^2>2\times\cdot 41V^2$, when the gradient wind is N or NE (*b*)
$\delta T^2>3\times\cdot 41V^2$, when the gradient wind is NW or E (*c*)

The above can be simplified further and put respectively in the following convenient forms:

$\delta T>\cdot 64\, V$ (*a*)
$\delta T>\cdot 91V$ (*b*)
$\delta T>1\cdot 1\, V$ (*c*)

The above conditions for the onset of sea breeze are given below in tabular form, it being remembered that δT has been expressed in °F and V in m. p. s.

For NNE-wind: condition $\delta T>\cdot 64V$		For NE and N-wind : condition $\delta T>\cdot 91V$		For E and NW-wind : condition $\delta T>1\cdot 1V$	
V=1,	$\delta T>64$	V=1	$\delta T>\cdot 91$	V=1,	$\delta T>1\cdot 1$
V=2,	$\delta T>1\cdot 3$	V=2,	$\delta T>1\cdot 8$	V=2,	$\delta T>2\cdot 2$
V=3,	$\delta T>1\cdot 9$	V=3,	$\delta T>2\cdot 7$	V=3,	$\delta T>3\cdot 3$
V=4,	$\delta T>2\cdot 6$	V=4,	$\delta T>3\cdot 6$	V=4,	$\delta T>4\cdot 4$
V=5,	$\delta T>3\cdot 2$	V=5,	$\delta T>4\cdot 5$	V=5,	$\delta T>5\cdot 5$
V=6,	$\delta T>3\cdot 8$	V=6,	$\delta T>5\cdot 5$	V=6,	$\delta T>6\cdot 6$
V=8	$\delta T>5\cdot 1$	V=8	$\delta T>7\cdot 3$	V=8,	$\delta T>8\cdot 8$
V=10	$\delta T>6\cdot 4$	V=10	$\delta T>9\cdot 1$	V=10	$\delta T>11\cdot 0$

In applying the above criteria, the gradient wind due to the general synoptic situation requires to be determined. This can be determined with reference to the morning synoptic chart prior to the onset of sea breeze. As, however, this will require some calculation, the mean of the upper winds at 0·2 and 0·5 km prior to the onset of sea breeze may be used as a close approximation.

Before applying the criterion we will also have to allow for any change in the gradient wind due to change in the synoptic situation by the time the sea breeze factor comes into play. This can usually be done from an examination of the synoptic chart. When, however, a western disturbance is not approaching the station, the change in the gradient wind factor between the morning and noon is not likely to be appreciable and this allowance will, in general, be unnecessary.

The criterion mentioned above was tried for the months of November—February 1934 and was found to give good results. The maximum temperatures at Manora (an island) and Drigh Road about 11 miles inland, were taken to represent temperatures over sea and land respectively.

In applying the criteria for forecasting purposes, the likely difference in maximum temperatures between Drigh Road and Manora will have to be judged in the morning. This can usually be done by observing the previous day's maximum temperatures and allowing for the probable change by noting the temperature tendency on the synoptic charts.

Before concluding, it is worthwhile emphasising that the criterion has been arrived at on several assumptions and approximations which are not strictly justifiable and the criterion, therefore, can be taken only as a rough guide. It, however, brings out clearly the relative magnitude of the two factors involved in the diurnal variation of winds in the winter months and it is hoped that it may serve as a useful guide in forecasting winds at the surface layers.

References

1. Jeffreys H.1922. Quarterly Journal, Roy. Met. Soc, Vol. 48, pp. 29—47.
2. Ramdas L.A.1931 India Met. Deptt. Scientific Vol. IV, No. 41 pp. 115—124.

TABLE I.

Drigh Road Ground Winds.

E: ple: ering of sea breeze with the progr of the day

Hours I. S. T.

Dates	11—12 hrs.	12—13 hrs.	13—14 hrs.	14—15 hrs.	15—16 hrs.	16—17 hrs.	17—18 hrs.	18—19 hrs	19—20 hrs.	20—21 hrs	21—22 hrs.	22—23 hrs.	23—24 hrs.
January 1937													
11th	..	..	SSW	SW	SW	SW	SW	WSW	WSW	W	NW		..
12th	..	..	..	SW	SW	SW	WSW	WSW	WSW	WSW	NW	..	..
17th	..	..	.	.	..	.	SSW	SSW	SW	WSW	WNW	..	..
25th	..	..	..	SW	SW	SW	SW	WSW	WSW	WSW	W	..	..
26th	..	..	..	..	..	SW	WSW	WSW	WSW	WSW	WSW	WNW	..
27th	..	..	..	..	SW	SW	SW	SW	WSW	W	WNW		..
28th	..	..	..	..	..	SW	SW	WSW	W	W	W	W	W
29th	..	..	..	..	..	WSW	WSW	WSW	WSW	WSW	W	NW	..
30th	..	..	..	..	SW	SW	SW	SW	WSW	CALM	CALM	CALM	..
31st	..	..	..	..	SSW	SSW	SW	WSW	W	CALM	CALM	..	..

TABLE II.

Drigh Road Ground Winds.

Examples of wind passing through a complete cycle in the course of the day by using Hours I. S. T.

Dates	8-9 hrs.	9-10 hrs.	10-11 hrs.	11-12 hrs.	12-13 hrs.	13-14 hrs.	14-15 hrs.	15-16 hrs.	16-17 hrs.	17-18 hrs.	18-19 hrs.	19-20 hrs.	20-21 hrs.	21-22 hrs.	22—23 hrs	23-24 hrs	24 next day
February 1936																	
3rd	NNE	NNE	ENE	ENE	E	E	ESE	ESE	ESE	SE	SSW	WNW	NW	NNW	NNW	N	NNE
8th	NE	ENE	..	..	ENE	SE	S	S	SW	WSW	WSW	W	NW	NNW	N	NE	..
January 1937																	
11th	NE	NE	E	SSE	S	SSW	SW	SW	SW	SW	WSW	WSW	W	NW	NE	NE	.
12th	NE	NE	NE	SSE	S	S	SW	SW	SW	WSW	WSW	WSW	WSW	NW	NNE	NE	..
17th	N	N	NNE	ENE	ENE	E	E	SSE	S	SSW	SSW	SW	WSW	WNW	WNW	WNW	NE
December 1937																	
1st	NE	NE	E	SE	ESE	SSE	SW	SSW	SSW	WSW	WSW	WSW	WSW	WNW	NW	N	NE

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INDIA METEOROLOGICAL DEPARTMENT

SCIENTIFIC NOTES

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Microseisms and Disturbed Weather

BY
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(Received on 30th January 1946)

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MICROSEISMS AND DISTURBED WEATHER

BY

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(Received on 30th January 1946).

Abstract.—Banerji, Lee, Ramirez and some other authors have studied the relationship between microseisms and disturbed weather. The seismograms of Alipore Meteorological Office give valuable information about disturbed weather at sea. A detailed examination of the Alipore seismograms and the synoptic charts for 8 years was undertaken to study the relationship between weather and microseisms. It is found that there are three types of microseisms recorded at Alipore—gusty wind type, monsoon type and storm type. The gusty wind type microseisms can be attributed to tilting of the seismograph pillar. The monsoon type microseisms are caused by monsoon in the Bay of Bengal and they also appear in the initial stages of a disturbance or with a far away storm over sea, and also sometimes when a disturbance is filling up Storm type microseisms are caused by depressions and storms in the Bay of Bengal, and sometimes also in the Arabian Sea, and they continue until the disturbance has weakened or crossed inland and moved away. Storm microseisms sometimes appear before the swell and strong wind of a disturbance reach the coast.

The study of microseisms was begun in the last century and some authors have examined the question of association of microseisms with disturbed weather. A bibliography on the subject has been given by Ramirez(1). One of the authors of this note, when he was in the Meteorological Office, Alipore, Calcutta, during the years 1937-40, derived considerable help in storm warning work from seismograms particularly during the period after September 1939, when radio silence was enforced on ships at sea due to war, and no weather reports were received from them. On a few occasions the seismograph charts were taken out and examined as many as six times during a day. The seismograms generally gave valuable information about disturbed weather at sea, and in some cases, when ships' observations were not available, gave indication of disturbed weather well out at sea which was not obtainable from the synoptic weather charts. A systematic examination of the Alipore seismograms was, therefore, undertaken to study microseisms mainly from the point of view of day to day forecasting. Some of the results found have, however, been compared with those obtained by other authors.

2. The Alipore Observatory possesses one horizontal Milne-Shaw seismograph in the N-S position with a magnification of 250 and a period of 12 seconds. This adjustment was found suitable for the study of the relationship of microseisms with weather. The instrument is placed in a room which has rooms on the East, North and West sides of it, but on the south side there is a verandah through the open arch of which, the sun shone during certain period of the day, on the south wall of the room and produced " creeping " of the record lines. A canvas screen covering the arch (provided in 1937) prevented the sun from shining directly on the wall, and considerably reduced the " creeping ". There are also two Omori horizontal seismographs in the observatory, but they are not sufficiently sensitive for the purpose in view. The records of the Milne-Shaw seismograph for the period 1931-1940 were taken up, but the records for the 2 years 1934-36, when the seismograph had been placed in E-W position, had to be rejected as a main water pipe, in an East-West direction and 25 feet to the south of the seismograph, produced spurious microseisms during certain hours of the day on account of increase and fluctuation of water pressure in the pipe. 8 years' seismograms of Alipore were thus studied, but for the sake of comparison, seismograms of Colaba, Kodaikanal and Agra for some periods of disturbed weather on sea were also examined. The Calcutta synoptic weather charts for the 8 years were scrutinised with a view to find out the dependence of microseisms upon weather.

3. Those seismograms of Alipore, which showed appreciable microseisms, were selected for tabulation. Generally, hourly measurements of amplitudes and periods were made. The measurements were made for the Colaba and Kodaikanal seismograms also, when the microseisms were appreciable, but only at intervals of 3 hours. The Agra seismograms did not, however, show any appreciable microseisms during any of the periods of disturbed weather in the sea for which the records were examined. Measurements of amplitude were carried out with a vernier scale from the most pronounced group of microseisms during an interval of 30 minutes ($\pm$15 minutes) centred at the hour, the amplitude being the mean value of 3 largest consecutive oscillations in the group. The mean period was calculated from the periods observed from several groups within the above interval of 30 minutes. Measurements were, however, not made when well marked oscillations due to earthquake shocks were superimposed.

General Behaviour.

4. The microseisms are generally absent from the Alipore Seismograms during the months January to March. During the other months, the microseisms are associated with gusty winds, with the onset, prevalence and intensification of monsoon in the Bay of Bengal, and with the formation and movement of depressions and storms in the Bay of Bengal, and sometimes also with storms in the Arabian Sea. The microseisms due to gusty winds, monsoon and storms (or depressions) are, however, of different types and can be easily distinguished from one another. This agrees generally with the observations of Banerji(2).

Land and Sea Breezes, Squalls and Microseisms.

5. Banerji(2) found that land and sea breezes of 20 miles or more per hour produced microseisms of periods of 10 to 30 seconds at Bombay, but land and sea breezes did not produce any microseism at Alipore. Even local strong winds and squalls at Alipore and neighbourhood have no definite effect. In *Tables 1* and *2* are given the winds at Alipore and Sandheads with corresponding values of period

and amplitude of microseisms on some days of thundersqualls and squalls. It will be seen that generally strong winds of thundersqualls or squalls of even 60 to 70 m.p.h at Alipore and neighbourhood on days of no monsoon or disturbance at sea did not cause any microseisms. Whenever there were appreciable microseisms, there was either monsoon or disturbed weather in the Bay (or Arabian Sea).

Gusty Winds and Microseisms.

6. Gusty winds produce a characteristic effect on the seismograms consisting of a series of bulges in the records. When the wind becomes gusty, these irregular bulges appear with some semblance of periodicity of about a minute. Banerji([2]) showed that similar bulges at Bombay, which had been noticed by him, could not be due to the free vibrations of trees and seismograph building which have a period of ·1 second.

7. Records for a few days have been reproduced in *Fig. I* These records may be compared with those in *Fig. II*. The small peaks in the traces (*a*) and (*c*) in *Fig. II* were caused by the tilts in the seismograph due to the presence of a large number of visitors in the vicinity of the instrument. The trace II (*b*) was due to a heavy roller working on the path adjacent to the seismograph room and illustrates the same effect enhanced because of the heavier weight of the roller. It was found that these peculiar irregular bulges, whenever they occurred, were either associated with gusty winds or were attributable to causes similar to those just mentioned above. Gusty winds would thus appear to produce the irregular bulges by causing tilts of the seismograph pillar. This agrees with the views of Whipple and Lee ([3]) who studied similar effects at Kew and Hamburg. The broad peaks of these bulges, however, appear to possess a fine structure, which is probably caused by short period vibrations of the ground accompanying the oscillations of the trees and the buildings in the compound.

Monsoon Microseisms.

8. As noted by Banerji ([2]), the microseisms associated with monsoon consist of uniform and steady vibrations and these could be easily recognised in the Alipore records. Monsoon microseisms are shown in *Fig. III*. The advance of monsoon in the SE Arabian Sea does not produce any microseisms at Alipore. The microseisms generally appear with the approach and strengthening of the monsoon in the Bay of Bengal, often even in the South Bay, but disturbances often occur in the Bay along with the approach or strengthening of the monsoon and the storm microseisms are then superimposed on the monsoon type. It is also found that often in the earlier stages of development of a disturbance, these monsoon microseisms first appear and later give place to the characteristic type of microseisms associated with disturbances. Sometimes after the disturbance weakens or passes inland and moves away, monsoon microseisms reappear In *Table 3* a few such cases have been given. The appearance of monsoon miscroseisms, when there is no monsoon, generally indicates the initial stage or the existence far away of a disturbance in the Bay.

9. The amplitudes of the monsoon microseisms do not appear always to depend upon the strength or proximity of the monsoon current in the Bay of Bengal. Vigorous or strong monsoon in the North Bay generally produce large microseisms, but

there were occasions when strong monsoon in the North Bay hardly produced any miscroseisms, while moderate monsoon in South Bay caused appreciable microseisms. In *Table 4* have been given a few occasions of different strength of monsoon with the maximum value of amplitude within ($\pm$) 12 hours, and the average period of microseisms at the hour. The periods of monsoon microseisms are from 3 to 7 seconds.

Microseisms and Atmospheric Oscillations.

(Pressure Fluctuations).

10. Ramirez(1), on an examination of seismograph and barograph records, concluded that atmospheric oscillations of short periods are not accompanied by microseisms. Lee(4) also found that there was no connection between microseisms and pressure fluctuations. Some well pronounced short period pressure fluctuations were selected from the records of Knudsen microbarograph at Alipore, but no microseisms were found to be associated with them.

Microseisms and Land Depressions and Storms.

11. In *Table 5*, some cases of depressions and storms, which both developed and filled up on land, are given along with the microseisms, if any, produced by them. It is seen from the table that microseisms do not depend upon the intensity or proximity of land depressions. In the last case mentioned even a severe storm, only about 70 miles NNE of Calcutta, did not produce any appreciable microseisms. It would appear, therefore, that depressions or storms of land origin do not cause microseisms; but, indirectly, if the disturbances cause a strengthening of the monsoon in the adjoining seas, monsoon microseisms make their appearance.

12. In this connection a question arises as to what happens when a disturbance from over the sea, passes inland and then travels as a land disturbance. It is seen that for sometime after the centre of the disturbance passes inland, the characteristic microseisms continue, but with continuously decreasing amplitudes. The reason is that when the centre of a disturbance has passed inland, part of the field is still over the sea and also the effect does not die out immediately. After some time the whole field passes inland, and the effect on seismograph is similar to that of a disturbance of land origin.

Microseisms Associated with Disturbances on the Sea.

13. The association of microseisms with barometric lows travelling over sea have been noted by many investigators. These microseisms belong to a characteristic type which may be called the " storm " type. The amplitudes are not uniform and regular like those of monsoon microseisms, but increase and decrease forming groupings of small and large amplitudes. The characteristics of microseisms can be seen in *Fig. IV* which is a reproduction of a portion of Alipore seismogram of the 16th October 1940, when there was a severe storm in the Arabian Sea close to Bombay.

14. These " storm " microseisms are generally, though not always, recorded at Alipore when there are disturbances over the Bay, particularly deep depressions and storms in the North and Central Bay. In *Table 6* are given the occasions, during the 8 years, when inappreciable or no microseisms were recorded at Alipore with disturbances in the Bay of Bengal. Storm microseisms are also sometimes, though not generally, recorded at Alipore with storms in the Arabian Sea.

15. The Gottingen school of seismologists and Gutenberg attribute the microseisms to the beating of surf produced by storms on distant rocky coasts. Byerly (5) found that some correlation existed between microseisms at Berkeley and the surf on nearby coasts, but there were periods when one was large and the other was not and vice versa. At Alipore, storm microseisms were, however, sometimes recorded when the disturbance was well away from the coast round the Bay, and before the strong winds and the swell produced by the disturbance reached the coast. A few such cases are given in *Table 7*. It was also found, on the other hand, that on a few occasions even when a storm or deep depression was close to the coast and was strongly affecting it, there were inappreciable or no microseisms at Alipore. It cannot be said that this might be due to the coasts affected not being rocky for other storms or deep depressions in the same regions have produced microseisms. It would thus appear that the microseisms cannot sometimes, at any rate, be attributed to the beating of the wind and swell of a disturbance on rocky coasts.

(*a*) *Period.*

16. Banerji(2) found that the storm microseisms have periods of 4 to 6 seconds and that the average monthly period decreases gradually during the first half of the year and increases thereafter. Lee(4) summarising his studies of microseisms at Eskdalemuir, Kew and De Bilt mentions that, in summer, the average period is 3 to 5 seconds, becoming larger in winter and confirms Banerji's conclusion regarding the annual variation. Ramirez(1) has noted similar seasonal characteristics in the records of St. Louis. In the records of Alipore it is noticed however that the periods during monsoon are smaller than during the rest of the year. The periods of storm microseisms at Alipore vary from 3 to 6 seconds. Ramirez's(1) conclusion that for the same storm the period is constant is not borne out by Alipore records. In *Table 8* some cases of disturbances have been given with the ranges in the periods and amplitudes of the associated microseisms. The values given are only for the stage when they were over sea and not after they had passed inland. It is seen that the period does not remain constant for the same disturbance, the variation being sometimes quite large. The records of Alipore also show that although the smallest periods of microseisms in any individual storm are associated with the largest amplitudes, a regular relationship like diminution in period with progressive increase in amplitude does not usually hold.

17. *Table 9* gives the period and amplitudes of some storms and depressions when approaching Alipore. It is seen that there is no definite change in the period with the approach to Alipore of a disturbance, nor there is any definite relation between the period and the distance of a disturbance from Alipore.

(b) *Amplitude*

18. In storm microseisms, the variations in amplitude and the groupings are characteristic. In the beginning the trace in the seismograms becomes thicker and assumes a sinusoidal character; the variations in amplitude and the groupings become clear later. A thickening of the trace with sinusoidal character indicates the occurrence or intensification of a disturbance out at sea An increase in amplitude indicates further intensification or movement towards Alipore, or both, of the disturbance while a decrease indicates the weakening or moving away from Alipore or both.

19. The seismograms of Bombay and Kodaikanal for the periods of some storms in the Bay of Bengal were examined and it was found that in many cases there were inappreciable or no microseisms at Kodaikanal and Bombay.

20. It was held by Banerji[2] and later confirmed by Ramirez[1] that the widespread character and intensity of a barometric low over the sea determine the size of the resulting amplitudes. One would except that the greater are the intensity and extent of the disturbance, the larger is the amplitude of microseisms produced, and that a depression of widespread character may have the same effect as a storm of small extent.

21. The variation of amplitude of Alipore storm microseisms is as given below :—

(i) Variation in amplitude and distance of disturbance from Alipore.

It is found that generally storms, even severe ones, in the Arabian Sea and distant parts of Bay of Bengal, produce microseisms of very small amplitudes or no microseisms at all. The severe Bombay storm of October 1940 is, however, an exception, as it produced at Alipore, at a distance of over 1,000 miles, larger microseisms than many of the storms in the North Bay within 200 miles from Alipore.

(ii) Amplitude and distance from the nearest coast.

It is seen that the microseisms somtimes become more pronounced at the time if the disturbance approaching or crossing the coast, irrespective of the fact whether it is moving nearer to or farther away from Alipore. *Table 10* gives some such cases It would thus appear that distance from the recording station is not always the determining factor though we cannot, however, definitely rule out, in such cases, the possibility of the disturbances having intensified while approaching the coast.

(iii) Amplitudes of storms of similar intensity and situated in the same locality.

Table 11 gives some groups of storms and depressions of similar intensity and situated in the same locality, and the associated microseisms. It will be seen from the table that similar storms situated in the same locality sometimes cause microseisms of different amplitudes at Alipore. Lee[4] had also noticed that the same size of microseisms are not always produced by similar conditions of " storminess " in the same place.

(iv) Maximum amplitude.

Table 12 gives the maximum amplitudes observed with a number of disturbances and the position of the disturbances at the time. This shows that the size of microseisms does not by itself, give definite information as to the position or even the intensity of a disturbance.

(v) *Increase in amplitude with intensification when a disturbance is stationary.*

It is found that intensification of a disturbance when stationary is accompanied by an increase in the size of microseisms. A few cases have been given in *Table 13.* When a disturbance is approaching Alipore and intensifying at the same time, the increase in amplitude is more pronounced In cases when a disturbance is weakening and approaching or receding and intensifying, the change in the size of microseisms depends upon the combined effect of movement and change in intensity.

(vi) *Variation of amplitude when a disturbance crosses coast and afterwards.*

It has already been stated that when a disturbance approaches coast, the microseisms increase in size provided the disturbance does not weaken at the same time. When a storm passes inland, there is a decrease, generally very rapid, in the size of microseisms. A storm also generally weakens after crossing coast. In *Table 14* are given some cases of storms with associated microseisms at the time of crossing and thereafter. With regard to the storm No I which presented an apparent anomaly in that the largest microseisms were recorded after the storm had passed the geographical coast, it may be stated that the Sunderbans region with the numerous wide creeks and mouths of rivers can probably be treated as part of sea instead of as part of land for the purpose in view. Many storms over this region behave as if they were still over the sea.

Conclusions Regarding Microseisms at Alipore.

2?. (a) Microseisms are of 3 types which can be easily distinguished from one another.

(i) Monsoon type—uniform and steady vibrations—period 3 to 7 seconds.

(ii) Storm type—the amplitudes are not uniform and regular but increase and decrease forming groupings of large and small amplitudes—periods 3 to 6 seconds.

(iii) Gusty wind type—series of uneven bulges with a sort of period of 1 minute or so.

(b) Strong surface winds, squalls or thundersqualls over land unassociated with storms and depressions from the sea, do not generally cause any appreciable microseisms.

(c) Depressions and storms of land origin, over land, do not produce any storm microseisms, but if they cause a strengthening of the monsoon over the sea, monsoon microseisms may appear.

(d) Advance of monsoon in Arabian Sea does not produce any microseisms. Advance and strengthening of monsoon in the Bay (even in the south Bay) generally produce monsoon microseisms.

(e) Often in the initial stages of development of a disturbance in the Bay of Bengal monsoon microseisms first appear and later give place to storm microseisms. Monsoon microseisms sometimes reappear after a disturbance weakens or crosses coast and moves away. Sometimes when the disturbance is, however, too far away or is weak, monsoon microseisms only are recorded.

(f) The appearance of monsoon microseisms, when there is no monsoon, indicates the initial stage or the existence of a far away disturbance over the sea.

(g) The more intense a disturbance and the nearer it is, the larger are the microseisms generally. The amplitude of microseisms is, however, not often a definite guide as regards the intensity or the distance from Alipore of a disturbance. Similar storms (or depressions) in the same locality also do not sometimes produce equally pronounced microseisms.

(*h*) Depressions and storms in the Bay generally give storm microseisms. The absence of microseisms generally indicates the absence of any deep depression or storm in the South Bay and of any depression or storm in Central and North Bay. The Andaman Sea off Pegu and the coast off Arakan are, however, somewhat peculiar in that sometimes even a storm in these regions does not produce microseisms.

(*i*) Storm microseisms definitely indicate a depression or storm at sea, generally in the Bay of Bengal, and sometimes in the Arabian Sea.

(*j*) Once the storm microseisms have appeared they do not vanish until the depression or storm fills up or it crosses coast and moves away.

(*k*) After storm microseisms have appeared, their increase means either the intensification of the disturbance or its movement towards Alipore or both. The decrease means either the disturbance has crossed coast or is weakening and in a few rare cases moving away from Alipore.

(*l*) There is also a tendency for microseisms to increase in amplitude when a disturbance approaches coast, but it is difficult to say whether this is due to its approaching coast or to an actual intensification of the disturbance. After a disturbance crosses coast, the microseisms decrease very rapidly, and thus it is generally possible to distinguish between a case of crossing coast and that of weakening of a disturbance.

(*m*) Storm microseisms sometimes appear before the swell and strong wind of a depression or storm reach the coast. On the other hand, there are occasions when even a storm close to the coast does not produce any or appreciable microseisms.

(*n*) Storms in the Bay of Bengal do not often produce any microseisms at Bombay and similarly storms in Arabian Sea do not often produce any microseisms at Calcutta.

(*o*) Storms in the Bay of Bengal and Arabian Sea generally do not cause microseisms at Agra and often also not at Kodaikanal.

(*p*) The period of storm microseisms does not remain constant for the same disturbance, the variation being sometimes quite large.

(*q*) The smallest periods of storm microseisms in any depression or storm are associated with the largest amplitudes, though there is no progressive change in period with increase in amplitude.

(*r*) There is no definite change in period of storm microseisms with the approach of a disturbance to Alipore.

(*s*) The gusty wind type microseisms are caused by the tilting of the seismograph pillar.

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TABLE 1.

Thundersqualls and strong winds at Alipore.

Date	Hours I. S. T.	Max speed of wind (B. S.)	Period (Secs.)	Amplitude (mikrones)	Remarks.
17-5-37	18·59	10	3·3	2·2	Gusty type of microseisms superposed.
20-5-37	16·10	12	3·3	2·2	Strong winds in NW Bay and neighbourhood. Gusty type of microseisms had ceased an hour earlier.
8-5-38	15·04	10		..	No microseisms.
7-5-39	18·04	12	8·6	1·6	Conditions unsettled off Coromondal coast.
10-5-39	13·30	11	..		No microseisms.
20-5-39	22·53	10	..		Do.
6-6-39	17·50	10	..	..	Do.
9-6-39	16·06	12	.		Do.
13-3-40	00·35	10	..	..	Do.
26-3-40	12·42	10	Not measurable	Not measurable	Weather thundery head Bay. Some gusty type also noticed.
4-5-40	17·19	11	.	..	No microseisms.
12-5-40	20·02	11	Not measurable	Not measurable	Gusty type microseisms only. Suspicion of unsettled condition off Tennasarim.
16-5-40	22·17	10	Not measurable	4·6	Advance of monsoon-south Bay.
15-6-40	10·37	12	..	..	No microseisms.

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TABLE 2.

Thundersqualls and local strong winds at Sandheads.

Date	Hours I. S. T.	Max. speed of wind (B.S.)	Period (Secs.)	Amplitudes (Mikrones)	Remarks.
7-5-37	12·40	7	3·2	4·0	Groupings of amplitude seen. Andaman Sea suspicious.
8-5-37	21·30	7	3	2 0	Do.
29-7-37	17·00	7	4	4·0	Land Depression near Berhampore. Monsoon moderate Bay.
30-7-37	08·00	7	4	4·4	Monsoon strong north of latitude 13 and moderate elsewhere.
21-5-38	02·00	11	3·3	2·2	Monsoon advancing Head Bay : moderate elsewhere.
17-4-39	22·0	7	..	.	No microseisms.
7-5-39	20·30	7	7·5	2·6	Unsettled conditions off Coromondal coast.
22-5-39	13·25	7	..	..	No microseisms.
12-6-39	18·00	7	..	..	No microseisms.
23-6-39	17·00	8	5	4·4	Monsoon vigorous N. Bay ; deep depression over SW Bengal
13-7-39	17·00	7	5 5	4·0	Unsettled conditions in Head Bay.
14-7-39	08·00	8	5·5	4·4	Vigorous monsoon in N. Bay ; strong elsewhere.
14-7-39	17·00	8	5	4·8	Do.
28-7-39	10·00	7	5	3·2	Monsoon strong and Central Bay , depression near Calcutta.
6-3-40	22·00	8	..	..	No microseisms.
14-3-40	00·55	10	..	..	No microseisms.
12-5-40	21·30	7—8	Not measurable	Not measurable	No appreciable microseisms.
31-5-40	15·00	9	Do.	Inappreciable	
7-6-40	12·00	7	..	.	No microseisms
8-6-40	09·40	8	..	..	Do.
10-6-40	11·00	8	..	..	Do
11-6-40	08·00	7	..	..	Do.
12-6-40	08·00	7	..	..	Do.
13-6-40	08·00	7	..	..	Do.
14-6-40	08·00	7	..	..	Do.
15-6-40	08·00	7	..	..	Do.
19-6-40	18·00	7	..	..	Do.

TABLE 3.

Monsoon microseisms followed by storm microseisms.

Date	Hour	Type of microseisms	Nature and position of depression and storm.
18-8-1931	0800	Uniform	Head Bay of Bengal unsettled.
to 19-8-1931	0700 } 0800 }	Groups . ..	As depression formed 120 miles SSE of Calcutta.
to 20-8-1931	0200	Groups	As storm 80 miles SSW of Calcutta
to 21-8-1931	0800	Uniform .. .	As storm had passed inland during previous night.
19-9-1932	0800	Uniform ..	As depression 200 miles south of Calcutta
20-9-1932	0800	Feeble groups ..	As storm 190 miles south of Calcutta.
	1100	Groups	The storm practically stationary
21-9-1932	2000	Uniform	The storm had already passed inland during the previous night
29-7-1933	1700	Uniform . ..	As depression 310 miles SSW of Calcutta
30-7-1933	0800	Uniform	The depression 350 miles SSW of calcutta.
31-7-1933	0800	Groups	The depression 350 miles SSW of Calcutta.
20-6-1937	0800	Uniform	As depression 140 miles SE of Calcutta.
21-6-1937	0800	Uniform	The depression 160 miles E of Calcutta.
22-6-1937	0800	Groups	The depression stationary.
23-6-1937	0800	Groups	As storm 240 miles ESE of Calcutta.
24-6-1937	0800	Groups	As storm 200 miles E of Calcutta.
24-6-1937	1700	Uniform	The storm weakened and passed inland into SE Bengal
4-12-1939	0200	No microseism ..	As depression near Car Nicobar.
	1700	No microseism ..	As storm near Car Nicobar.
5-12-1939	0800	Uniform .. .	The storm 900 miles south of Calcutta.
6-12-1939	0800	Groups	The storm 750 miles south of Calcutta.
7-12-1939	0800	Groups . ..	As severe storm 600 miles SSW of Calcutta.
9-12-1939	0800	Uniform . ..	The severe storm weakened into depression.
1-8-1940	0800	Uniform	Head Bay unsettled
	2300	Uniform	As depression 60 miles ESE of Calcutta.
2-8-1940	0200	Feeble groups ..	The depression stationary.
	0800	Groups	As storm 60 miles ESE of Calcutta.
	1700	Groups indistinct .	The storm passed further inland into Bengal (50 miles E of Calcutta).

TABLE 4.

Monsoon microseisms.

Date	Nature of monsoon	Average Period (Secs.)	Max. amplitude. (Mikrones).
10-6-31	Monsoon generally moderate over the whole of Bay of Bengal.	4·3	2·2
15-6-31	Do. ..	3·5	2·6
10-8-31	Monsoon strong N and Central Bay	.	No microseism.
21-8-31	Monsoon generally moderate over whole Bay	4·0	2·8
13-6-32	Monsoon vigorous North and Central Bay; strong south Bay.	3·5	4·0
15-7-32	Monsoon strong north and central Bay	3·8	4·4
28-7-32	Monsoon strong north and central Bay .. .	4·0	2·8
1-8-32	Monsoon strong off Orissa Ganjam coast; generally moderate elsewhere.	3·8	3·0
3-6-33	Monsoon strong in Bay	4·3	2·2
19-7-33	Monsoon generally moderate in Bay	4	1·6
11-8-33	Monsoon generally moderate in Bay . ..	3·8	1·8
22-9-33	Monsoon strong northwest Bay	4	2·8
20-10-33	Monsoon moderate off Coromondel Circars Coast ..	4	1·6
22-5-37	Monsoon moderate south and central Bay	3·2	2·2
12-6-37	Monsoon strong south Bay and generally moderate elsewhere in Bay.	3·5	2·4
28-6-37	Monsoon strong in Bay	4	3·4
30-6-37	Monsoon moderate in Bay	4·3	2·4
14-7-37	Monsoon moderate N and Central Bay; weak elsewhere in Bay.	4·6	3·0
26-7-37	Monsoon strong in Bay	5	5·2
4-8-37	Monsoon moderate in Bay	5	3·6
4-9-37	Monsoon strong north and central Bay and moderate elsewhere in Bay.	4·6	2·8
21-5-38	Monsoon generally moderate in Bay . ..	3·3	2·4
29-5-38	Monsoon strong head Bay and generally moderate elsewhere in Bay	4	1·4
11-6-38	Monsoon strong in Bay	5·5	2·2
14-6-38	Monsoon strong north Bay; generally moderate elsewhere in Bay.	5	2·4
20-6-38	Monsoon generally moderate in Bay	5	2·0

TABLE 4—*concld.*

Date	Nature of monsoon	Average Period (Secs.)	Max. amplitidue. (Mikrones).
11-7-38	Monsoon vigorous north of lat 16 and generally moderate elsewhere in Bay.	5	3·6
14-8-38	Monsoon generally moderate in Bay	4·6	1·2
30-9-38	Monsoon strong south of lat 12 and moderate elsewhere in Bay	5	2·0
16-5-39	Monsoon strong south and central Bay and extending north Bay.	7 4	4·0
18-5-39	Monsoon moderate in Bay	5·5	2·6
10-6-39	Monsoon strong SW Bay and generally moderate elsewhere in Bay	5	4·0
11-7-39	Monsoon strong north of lat. 15 and generally moderate elsewhere.	5·5	3·4
12-7-39	Monsoon strong in Bay	5·5	3·0
14-7-39	Monsoon vigorous north Bay and generally strong elsewhere.	5·5	5·6
22-6-40	Monsoon strong south and central Bay ; moderate north Bay.	5·5	2·2
28-6-40	Monsoon strong in Bay	6	3·0
4-7-40	Monsoon strong north Bay ; moderate elsewhere in Bay	5	2·8
18-7-40	Monsoon moderate in Bay	4	4·4
31–7–40	Monsoon moderate in Bay	5·5	2·4
4-8-40	Monsoon generally moderate in Bay	4·3	1·4
23-8-40	Monsoon strong in Bay	5	3·2

TABLE 5.

Land depressions and storms.

Depression or storm	Max. amplitude (Mikrones)	Type of microseisms	Remarks.
1. A shallow land depression formed over west Bengal by the morning of the 30th July 32 and moving westwards through Chota Nagpur filled up over east U P. on 1st August 1932.	1 8	Uniform	Monsoon active in Bay.
2. A land depression which formed near Lucknow on the morning of 7th July 36 moved northwes wards and filled up near Bareilly by the morning of the 12th.	Nil	..	
3. A land depression formed near Pendra by the 17th July 37 and merged into the seasonal trough of low pressure within the next 25 hours.	Nil	..	
4. A land depression . 1938			
10th July 0800—105 miles north of Calcutta	2 0	Uniform	Monsoon generally moderate in Bay.
11th July 0800—140 miles NNW of Calcutta	3 6	,,	Monsoon vigorous north of lat. 16 and generally moderate elsewhere.
12th July 0800—300 miles WNW of Calcutta	4·4	,,	Do.
13th July 0800—Became unimportant ..	2·4	,,	Do.
5. Land depression : 1939			
14th July—90 miles north-west of Calcutta..	5·6	Uniform	Monsoon vigorous north Bay and strong elsewhere.
15th July—240 miles WNW of Calcutta ..	4·8	Uniform	Monsoon strong Bay.
16th July—410 miles WNW of Calcutta ..	4 0	,,	Do.
17th July—410 miles WNW of Calcutta ..	2·4	,,	Monsoon strong central Bay and moderate elsewhere.
18th July—Unimportant	2·0	,,	Do
6. Land storm of 29th July to 7th August .. 1939			
29th July 0800—A depression 150 miles NE of Calcutta.	1·6	Uniform	Causing unsettled weather Head Bay ; elsewhere moderate monsoon.
30th July 0800—A deep depression 110 miles NE of Calcutta.	2·2	,,	Causing strong monsoon with squally weather and rough seas in N. Bay, elsewhere moderate monsoon.
31st July 0800—A deep depression 105 miles N of Calcutta.	3·0	Uniform	Monsoon strong Head Bay, moderate elsewhere.
1st Aug. 0800—A storm 60 miles NE of Calcutta.	2·4	,,	Do.
2nd Aug. 0800—A severe strom 150 miles NE of Calcutta.	Inappreciable		
3rd Aug. 0800—A severe storm 70 miles NNE of Calcutta.	,,		
4th Aug. 0800—A depression 165 miles NW of Calcutta.	Inappreciable till 7 hrs.		

TABLE 6.

Disturbances in Bay when none or inappreciable microseisms were recorded.

Disturbance in the Bay of Bengal.	Period when the disturbance was in the Bay	Inappreciable or no microseisms.
1. Shallow depression—A shallow low formed over northwest Bay extending to Chota Nagpur. Passed inland on the 27th.	26-27 Aug 31	Inappreciable.
2. Shallow depression—Formed over central Bay on the 17th. Passed inland across north Madras coast as a wave of low pressure on the 19th	17-19 Sep 31	Do.
3 Depression—Formed over northern part of Bay on the 22nd. Moving westwards, passed inland across Circars coast by the 25th	22-26 Sep. 31	Do.
4. Depression—Formed off south Ceylon coast on the 9th passed into the Arabian Sea, and then moving northwards, became unimportant near Goa.	9-14 Dec 31	Do.
5. Depression—Formed over southwest Bay on the 30th Oct. Moving northwards crossed Circars by the 2nd November	30th Oct.—2nd Nov. 1932.	Inappreciable.
6. Cyclonic storm—Formed over south Bay. Moving towards Madras, weakened into a depression on the 25th on approaching it and then passed inland by the 26th.	23-26 Nov. 32	Do.
7. Cyclonic storm—started from southeast Bay as depression on 22nd, intensified into storm over east central Bay on the 23rd. Approaching Akyab, the storm weakened on 26th and became unimportant after passing inland.	22-26 May 33	Inappreciable
8. Shallow depression—Formed in the north Andaman Sea on 3rd, weakened into a trough of low pressure by the 6th and moving westwards passed across south Peninsula into Arabian Sea by 10th. It became unimportant on 13th.	3-13 Nov. 33	Do.
9. Depression—Formed east of Ceylon on 23rd. Moving westwards into Arabian Sea, became unimportant off Malabar on the 26th	23-26 Jan. 34	Inappreciable.
10. Shallow depression—Formed over west central Bay on the 26th. Moving north-westwards crossed Orissa coast by the 27th.	26-27 Jun. 34	Do.
11. Cyclonic storm—Formed over southwest Bay on the 25th Moving westnorthwestwards, weakened while approaching Coromondel coast, and became unimportant after passing inland on 28th	25-27 Nov. 34	No microseisms.
12. Shallow depression—Formed off Orissa coast on the 25th. Moving northwestwards crossed Orissa coast by the 26th.	25-26 Jun. 35	Inappreciable.
13. Depression—Formed over central Bay on the 14th. Moving towards northwest angle Bay, passed inland by the 21st.	14-21 Jul. 35	Do.
14. Shallow depression—Formed over north Bay on 20th. Moving north northwestwards passed inland by the 21st.	20-21-Jul. 35	Do.
15 Deep depression—Formed over north Andaman sea on 1st and then moving into the Bay off Arakan coast filled up by the 3rd.	1-3 Nov 35	Do.
16. Severe cyclonic storm—Formed over southwest Bay on the 13th. Weakened into deep depression after passing inland near Negapatam.	13-15 Nov. 35	Do.

Disturbance in the Bay of Bengal.	Period when the disturbance was in the Bay.	Inappreciable or no microseisms.
17. Depression—Formed over north Bay on 2nd. Moving northwards passed inland near Balasore by the 3rd.	2-3 Jul. 36.	Nil
18. Deep depression—Started from north Bay on the 25th as a shallow depression. Moving westwards, became deep and passed near Callingapatam by 29th	25th Aug-1st Sep. 1936.	Inappreciable.
19. Depression—Formed over south Bay on the 4th. Moving towards Madras passed inland by the 7th.	4-7- Nov. 36	Do.
20. Depression—Formed over southwest Bay west of Andaman on the 2nd. Moving northwards became unimportant by the 6th in the neighbourhood of Andamans	2-6 Dec. 36	Do.
21. Depression—Formed over southwest Bay east of Ceylon on the 3 .th. Passed towards the southwest Ceylon on the 31st and became unimportant.	30-31 Dec.36	Do.
22. Deep depression—Formed over south Bay. Moving westnorthwestwards crossed coast between Madras and Nellore.	14-17 Apr. 37	Nil.
23. Severe cyclonic storm—Formed over north Andaman Sea. Moving northwestwards, it crossed coast near Diamond Ild.	27-30 Apr. 37	Nil.
24. Depression—Formed over northwest Bay. Moving westnorthwestwards crossed coast near Balasore	1-3 Jul. 37	Nil.
25. Depression—Formed over northwest Bay. Moving westnorthwestwards crossed coast near Cuddalore.	30th Sep.—2nd Oct 1937.	Nil.
26. Deep depression—Formed over southwest Bay. Moving northwestwards crossed coast near Cuddalore.	13-16 Nov. 37	Nil.
27. Cyclonic storm—Formed over central Andaman sea. Moving north north east wards weakened in the Gulf of Martaban.	26-29 Dec. 37	Nil.
28. Severe cyclonic storm—Formed over central part of south Bay. Moved westnorthwestwards at first and approaching Palk Strait moved southwestwards ; passed into the southeast Arabian Sea where it filled up.	7-12 Jan. 39	Inappreciable.
29. Cyclonic storm—Formed over south Bay off Ceylon. Moving northnorthwestwards crossed west between Cuddalore and Negapatam.	11-14 Apr. 39.	Nil.
30. Depression—Formed over east Central Bay off Arakan coast. Moving northnorthwestwards parallel to coast it crossed southeast Bengal coast.	17-27 Sep. 39.	Nil.
31. Depression—Formed over east central Bay off Arakan coast. Moving northwestwards crossed Bengal coast.	29th Sep. to 2nd Oct. 1939	Inappreciable.
32. Deep depression—Formed over west central Bay. Moving westnorthwestwards crossed coast near Nellore.	20-25 Oct. 39	Do.
33. Deep depression—Formed over west central Bay. Moving northwestwards, it weakened and crossed coast as a low pressure wave.	29-31 Oct. 39	Do.

TABLE 7.

Appearance of storm microseisms before wind or swell of disturbance reached coast.

Date	Position of disturbance
10th July 1937 . . .	Depression about 250 miles southsouthwest of Calcutta.
27th September 38	Deep depression about 500 miles southsoutheast of Calcutta.
8th November 1938 . .	Storm about 750 miles south of Calcutta.
6th December 1939	Storm about 750 miles south of Calcutta.

TABLE 8.

Range of period and amplitude of microseisms with disturbances.

Date.	Brief description of course of depression or storm.	Range of period (Secs.)	Range of amplitude (Mikrones).	Remarks.
30-6-31 to 1-7-31	Unsettled conditions over N.W. Bay developed into a shallow depression near Sandheads and passed into south Bengal	3·3 to 5·0	1·6 to 3·0	Maximum amplitude with minimum period observed at the time of passing inland.
4-10-31 to 5-10-31	A shallow depression formed off Orissa coast and passed inland between Balasore & Saugar Ild.	3·0 to 3·3	1·8 to 6·4	(Amplitude) was 1·8 at the time of crossing coast and maximum when the depression was 50 miles N W. of Sandheads.
18-7-32 to 21-7-32	A shallow depression off Orissa Bengal coast, deepened and passing close to Sandheads entered Orissa coast.	3·0 to 4·6	2·2 to 4·0	Maximum (Amp) with minimum period obtained with deep depression 165 miles S S W of Calcutta.
8-8-33 to 9-8-33	A deep depression formed off Arakan coast crossed the Orissa coast.	3·5 to 4·3	1 0 to 4·0	Maximum (Amp.) obtained with deep depression 185 miles south of Calcutta.
16-11-33 to 17-11-33	A storm centred off Coromondel coast intensified and crossed it between Nellore and Masulipatam.	4 to 5	1·0 to 2·8	Maximum (Amp) with minimum period obtained at the time of crossing coast.
20-6-37 to 24-6-37	A depression centred off Bengal coast intensified into a storm near Cox's Bazaar, then weakened and passed into S E. Bengal.	3 8 to 4·6	2·0 to 16·6	Maximum (Amp.) obtained after intensification into storm.
13-10-37 to 15-10-37	A storm over north Bay off Orissa coast, intensified further, crossed coast near Chittagong.	3·5 to 5	2·4 to 41 2	Maximum (Amp.) obtained when storm 80 miles SE of Calcutta
5-10-38 to 10-10-38	A depression formed E. Central Bay, intensified into severe storm and crossed coast near Gopalpur.	3·8 to 5	1·2 to 7 8	Maximum (Amp.) obtained at the time of severe storm crossing coast
28-8-39 to 29-8-39	A depression formed off Arakan coast, then intensified into storm and passing close to Sandheads, crossed coast near Balasore.	4 to 5	1·6 to 13·6	Maximum (Amp.) obtained at the time of crossing coast.
5-12-39 to 6-12-39	A storm over SE Bay became severe and approached Orissa coast and then filled up off Orissa coast.	4·3 to 5 5	1·6 to 4·8	Maximum (Amp.) obtained after the storm had become severe
6-7-40 to 8-7-40	A depression formed over Head Bay, intensified into storm and entered Bengal	3·5 to 4·3	2·4 to 8·2	Maximum (Amp.) obtained when storm was near Calcutta.

TABLE 9.

Disturbances approaching Alipore.

Depression or storm with date.	Distance and bearing from Calcutta for successive positions of centre	Period. (Secs.).	Amplitude (Mikrones).
1. Bay storm 14th to 16th May 1931.	(a) As depression 500 miles south of Calcutta	4	1·8
	(b) As depression 440 miles south of Calcutta	4	1·6
	(c) As storm 380 miles S E of Calcutta	3 8	2·0
	(d) Storm crossed Arakan coast 440 miles ESE of Calcutta.	3 8	2·0
2. Bay depression 3rd to 5th Oct 1931	(a) Depression 310 miles S of Calcutta	3 3	2·8
	(b) Depression 270 miles S of Calcutta	3 2	6·0
	(c) Depression 95 miles SW of Calcutta	3·2	3·8
	(d) Depression crossed coast between Balasore and Saugar Ild 75 miles SW of Calcutta	3·2	1·8
3. Bay depression 24th to 27th Oct. 1931.	(a) Shallow depression 435 miles SSW of Calcutta.	Inappreciable	Inappreciable.
	(b) As depression 320 miles SSW of Calcutta	Do.	Do.
	(c) As deep depression 270 miles south of Calcutta	3·3	3·6
	(d) As deep depression 230 miles south of Calcutta	3·3	4·2
	(e) As deep depression 165 miles south of Calcutta.	3 8	3·0
	(f) As depression 130 miles S of Calcutta ..	3	1·8
	(g) Depression unimportant, 130 miles south of Calcutta.	3·3	1·4
4. Bay severe storm 23rd to 24th May '32.	(a) As depression 460 miles SSW of Calcutta	3 8	2·4
	(b) As deep depression 380 miles SSW of Calcutta.	3·5	2·8
	(c) As storm 290 miles SSW of Calcutta ..	3·5	6·4
	(d) As severe storm 110 miles SSW of Calcutta.	3·3	13·0
	(e) Severe storm crossed coast 50 miles SSW of Calcutta.	3·5	17·2
5. Bay deep depression 18th to 21st Jul. '32.	(a) As shallow depression 200 miles south of Calcutta.	3 8	2·6
	(b) As deep depression 200 miles south of Calcutta.	3·2	2·6
	(c) As deep depression 165 miles SSW of Calcutta.	3·2	3·4
	(d) As deep depression 110 miles SSW of Calcutta.	3·8	2·8
	(e) As deep depression 130 miles SW of Calcutta.	4·3	2·4
6. Bay depression 31st to 1st Aug. '33.	(a) As depression 325 miles SSW of Calcutta	3·8	2·0
	(b) As depression 295 miles SW of Calcutta .	3·8	2·6
	(c) Depression crossed coast 285 miles S W of Calcutta.	4	2·6
7. Bay storm 18th to 21st Sep. '33.	(a) As storm 315 miles SSE of Calcutta ..	..	Inappreciable.
	(b) As storm 285 miles SE of Calcutta . ..	4	1·2
	(c) As storm 170 miles SSE of Calcutta .	4	2·0
	(d) As storm 105 miles SSE of Calcutta ..	3·5	2·0
	(e) Storm crossed about 55 miles SSW of Calcutta.	4	1·8
8. Bay depression 10th, 11th Jul. '37.	(a) As depression 240 miles SSW of Calcutta	4·3	1·6
	(b) As depression 190 miles SSW of Calcutta	4	1·6
	(c) Depression crossed coast 190miles SW of Calcutta.	3·8	2·4
9. Bay storm 22nd, 23rd Jul. '37.	(a) As deep depression 240 miles south of Calcutta.	5	2·8
	(b) As deep depression 200 miles south of Calcutta.	4	4·0
	(c) As storm 130 miles SSW of Calcutta ..	3·3	10·4
	(d) Storm crossed coast 130 miles SW of Calcutta.	3·8	12·0

TABLE 10.

Increase of amplitude on approaching coast.

Depression or storm with dates taken.	Successive distance and bearing in miles from Calcutta.	Nearest coast and distance in miles from it.	Amplitude (Microns).	Remarks.
1. A deep depression 24th to 25th July 1932 in Bay.	165 SSW ..	75 Orissa-Bengal ..	2·0	
	190 SSW ..	75 Orissa .. .	2·6	
	190 SSW ..	Crossed Orissa .	3·2	
2. A depression 2nd to 3rd Sep. '32 in Bay.	250 SSW .	80 Orissa	Inappreciable.	
	280 SSW ..	55 Orissa	2·0	
	250 SSW ..	Crossed Orissa .	2·6	
3. A depression 10th to 11th July '37 in Bay.	240 SSW ..	120 Orissa	1·6	
	190 SSW ..	65 Orissa	1·8	
	190 SSW .	Crossed Orissa ..	2·6	
4. A deep depression 27th to 29th Sep. '38 in Bay.	440 S .	340 Orissa	1·2	
	480 SW ..	165 Circars ..	1·4	
	555 SW ..	85 Circars ..	1·4	
	635 SW ..	Close to Circars .	1·6	
	635 SW ..	Crossed Circars .	2·2	
5. A storm on the 29th Aug.'39 in Bay.	110 S ..	70 Orissa .. .	8 6	
	115 SW ..	Crossed Orissa ..	13·6	
6. A severe cyclonic storm 15th to 16th Oct. '40 in the Arabian Sea.	1230 WSW ..	220 Konkan-Kanara	1·8	A deep depression.
	1200 WSW .	150 Konkan-Kanara	2 4	A storm
	1200 WSW .	150 Konkan-Kanara	4·6	A severe storm.
	1100 WSW ..	70 Konkan-Kanara .	6·2	A severe storm.
	1000 WSW ..	Close to Konkan coast near Bombay.	15 4	A severe storm.
	1000 WSW ..	Passed inland but very near Konkan coast.	4 6	Weakened into storm.
7. A depression 12th to 13th Aug. '40 in the Bay of Bengal.	245 SSW ..	95 Orissa .. .	1·2	
	320 SSW .	Near Orissa coast ..	2·2	
	320 SSW ..	About to cross coast	5·2	
	320 SSW ..	Passed inland .	4·4	

TABLE 11.

Microseisms and similar disturbances in the same locality.

Depression or storm with date.	Position (distance and bearing from Calcutta).	Amplitude (Mikrones).
Deep depression in Bay, 20-7-32	110 miles SSW ..	2·8
Deep depression in Bay, 27-9-37	Do. ..	4·6
Deep depression in Bay, 21-7-39	Do. ..	2·6
Storm in Bay, 23-6-39	110 miles SSW ..	3·8
Storm in Bay, 29-8-39	Do. ..	8·6
Shallow depression in Bay, 1-7-31	110 miles SSW ..	2·2
Shallow depression in Bay, 20-7-39	Do. ..	1·8
Storm in Bay, 7-7-40	80 miles S ..	4·4
Storm in Bay, 14-10-37	Do. ..	41·2
Storm in Bay, 23-6-39	110 miles S ..	4·8
Storm in Bay, 29-8-39	Do. ..	11·0

TABLE 12.

Position of disturbance when maximum amplitude was recorded.

Date when amplitude was maximum.	Nature of disturbance.	Distance from Calcutta when the amplitude was maximum.	Amplitude (Mikrones).
16-5-1931	Storm	400 miles SE	2·2
20-8-1931	Storm	90 miles SSW	3·4
4-10-1931	Shallow depression	270 miles S .. .	6·4
24-5-1932	Severe storm	50 miles E	21·6
24-10-1932	Storm	370 miles SSW	3·0
15-12-1933	Storm	900 miles SW	2·4
4-10-1936	Severe storm	190 miles SW	10·0
23-6-1937	Storm	240 miles ESE	16·6
11-7-1937	Depression	200 miles SW	2·6
20-7-1937	Storm	130 miles SW	14·6
14-10-1937	Storm	80 miles SE	41·2
29-9-1938	Deep depression	650 miles SW	2·2
9-10-1938	Severe storm	250 miles SW	7·8
25-11-1938	Severe storm	640 miles SW . ..	2·4
23-6-1939	Storm	110 miles S	4·8
29-8-1939	Storm	110 miles S	11·0
7-12-1939	Severe storm	600 miles SSW	4·8
29-6-1940	Storm	160 miles SW	5·8
2-8-1940	Storm	50 miles E	5·6
27-8-1940	Depression	60 miles SE	5·4
16-10-1940	Severe storm	1,000 miles WSW	15·4

TABLE 13.

Intensification of disturbance without movement.

No.	Date.	Hours.	Stages.	Distance from Alipore (Miles)	Amplitude (Mikrones).
1	14-6-1933	17	As storm .. .	250 SSW ..	1·4
	15-6-33	2	As storm	Do. .	2·2
2	24-7-1933	8	As shallow depression	155 SE ..	1·6
	24-7-1933	17	As depression	Do. ..	2·4
3	2-8-1933	17	As deep depression ..	210 S	2·8
	2-8-1933	23	As deep depression (It then moved and became storm by 8 hrs of 3-8-19 about 110 SSW of Alipore).	Do.	4·4
4	22-6-1937	23	As deep depression ..	240 ESE ..	4·8
	23-6-1937	8	As storm . ..	Do. ..	6·4
	23-6-1937	17	As storm	Do. ..	16·6
5	27-9-1937	20	As deep depression ..	110 SSW ..	2·8
	27-9-1937	23	As storm	Do. ..	4·8
6	9-10-1938	14	As storm	250 SW ..	7·0
	9-10-1938	19	As severe storm	Do. ..	7·8
7	20-7-1939	8	As depression	110 S	2·0
	21-7-1939	8	As deep depression ..	Do. ..	2·8
8	30-6-1940	2	As deep depression ..	90 SSE ..	2·2
	30-6-1940	8	As storm	Do. ..	2·8
9	2-8-1940	2	As depression	60 SE	2·8
	2-8-1940	8	As storm	Do. ..	4·0

TABLE 14.

Disturbances crossing coast.

Nature of disturbance and date.		Hour.	Location of disturbance.	Amplitude (Mikrones)	Remarks.
1. Storm	24-5-32	11	Crossing S. Bengal coast near Saugar Ild.	17·0	
		14	Crossed coast and 50 miles east of Alipore.	21·6	
		17	75 miles ENE of Alipore ..	12 0	Weakening.
2. Depression	11-7-32	8	Depression about to cross coast between Balasore & Saugar Ild.	4 2	
	,,	17	Passed inland	3·8	Weakening.
	,,	22	Orissa	2·6	Weakened further.
3. Storm	15-6-33	17	About to cross coast between Chandbali and Balasore.	2·6	
	,,	23	Crossed coast & weakened ..	2	
	16-6-33	8	....	1·8	Weakened further.
4. Severe storm.	17-11-33	17	About to cross coast between Nellore & Masulipatam.	2·8	
	18-11-33	2	Passed inland	1·8	
5. Storm	23-7-37	17	About 50 miles from Orissa coast.	11·0	
	,,	20	About to cross coast between Chandbali and Balasore.	14·6	
	24-7-37	2	Passed inland and weakening	12·0	
	,,	8	A deep depression over Orissa	6·4	
6. Severe storm.	9-10-38	19	About to cross coast 300 miles SW of Alipore.	7·8	
	10-10-38	8	Passed inland near Gopalpur	5·2	
	,,	17	...	3·8	Weakened further.
7. Storm	29-8-39	17	Storm crossing Orissa coast near Balasore.	13·6	
	30-8-39	2	Passed inland . .	6·8	
	,,	8	....	5·0	Weakened further.
8. Depression.	12-8-40	17	Close to coast near Gopalpur	2·0	
	13-8-40	2	About to cross coast near Gopalpur.	3·6	
	,,	8	Crossed coast	4·4	
	,,	11	....	3·6	Weakened.
	,,	14	....	3·0	Weakened further.

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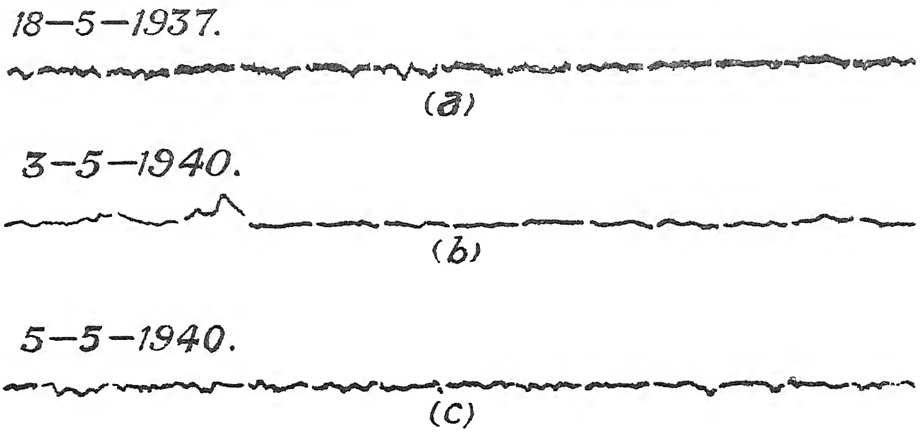

Fig 1. *Gusty wind microseisms*

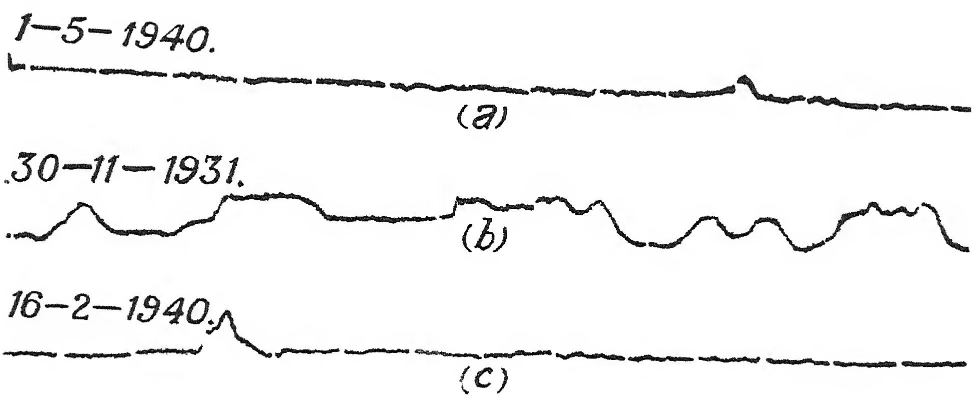

Fig. 2. *Microseisms produced by parties of Visitors and heavy roller.*

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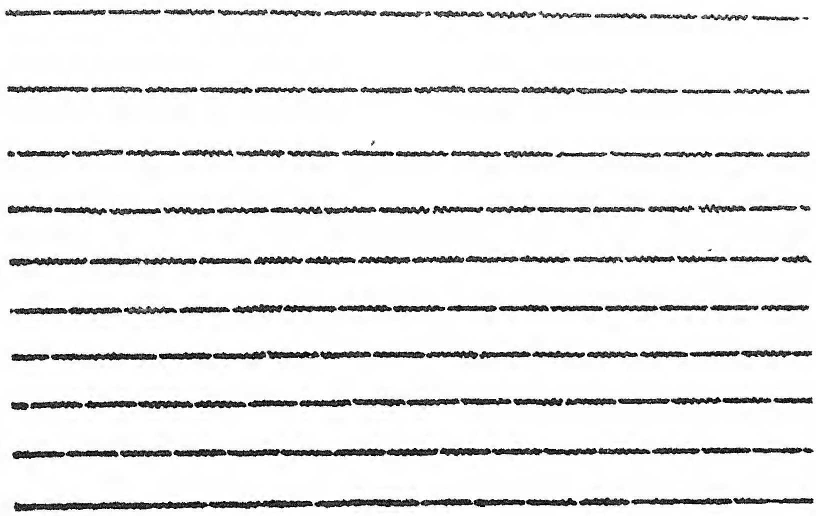

Fig. 3. Monsoon Microseisms.

20-9-1944.

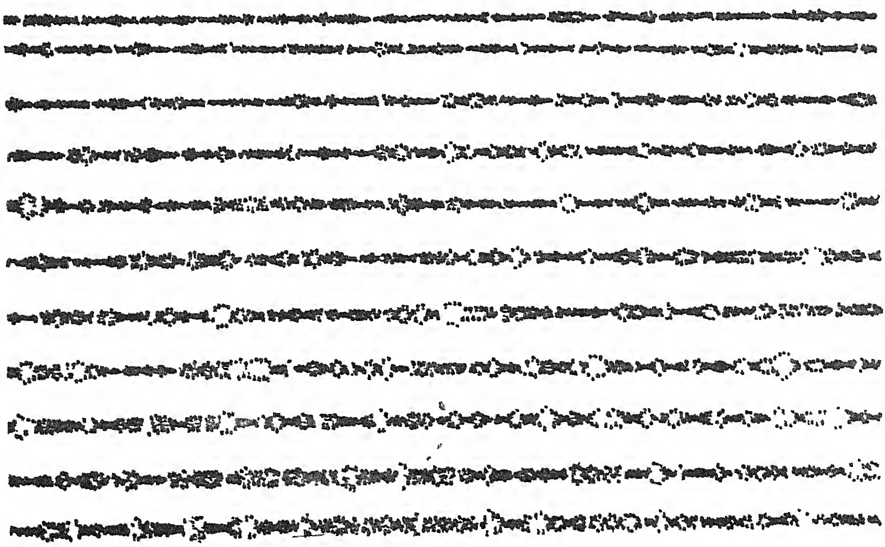

Fig. 4. Storm Microseisms

16-10-1940.

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Regression of climatic elements on Latitude, Longitude and Elevation in India

Part I Mean Temperature

BY

P. JAGANNATHAN

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REGRESSION OF CLIMATIC ELEMENTS ON LATITUDE, LONGITUDE AND ELEVATION IN INDIA.

PART I—Mean Temperature.*

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Abstract.—The paper deals with the relationship between the position and altitude of a place and the average temperature conditions prevailing there. The mean monthly and annual temperatures at 167 meteorological stations in India have been correlated with their values of latitude, longitude and altitude. The regression formulae expressing the mean temperature in each month and the year in terms of the latitude, longitude and altitude have been evolved and discussed. The multiple correlation coefficients obtained are all high ranging from ·87 to ·97. The computations have also been carried out separately for the four portions into which India has been divided by the tropic of Cancer and the meridian of 78°E. One remarkable fact noticed is that the regression coefficients on altitude in all the regions and in all the seasons are very significant and are fairly uniform varying slightly about a value of 3°F per 1000 ft., which is the value of the normal lapse rate of temperature in the free atmosphere. The analysis was repeated for different ranges of height and it was found that the dependence of temperature on altitude was significant only in regions above 1000 ft.

* Abstract of the paper was read before the Indian Science Congress in 1939.

From (3) we see that as $\frac{\delta t}{\delta \varphi} = b_1$, $\frac{\delta t}{\delta \lambda} = b_2$ and $\frac{\delta t}{\delta h} = b_3$.

The partial regression coefficients are actually the gradients of temperature towards north, towards east and vertically upwards. It can be readily seen that (1) gives the equation of the isothermal surfaces as computed. The mean sea level isotherms are given by the equation :

$$T = A + b_1 L + b_2 l \qquad (4)$$

$\tan^{-1} b_1/b_2$ is the angle which the isotherms make with the meridians and $1/\sqrt{b_1^2 + b_2^2}$ is the distance between consecutive unit isotherms.

Regression Coefficients.—The coefficients b_1, b_2 and b_3 in equation (3) for each month and the year were determined in the usual manner by solving the normal equations :

$$b_{r1} \Sigma \varphi^2 + b_{r2} \Sigma \varphi\lambda + b_{r3} \Sigma \varphi h = \Sigma \varphi t_r \quad \cdots \quad (5)$$

$$b_{r1} \Sigma \varphi\lambda + b_{r2} \Sigma \lambda^2 + {}_{r3} \Sigma \lambda h = \Sigma \lambda t_r \quad \cdots \quad (6)$$

$$b_{r1} \Sigma \varphi h + b_{r2} \Sigma h\lambda + b_{r3} \Sigma h^2 = \Sigma h t_r \quad \cdots \quad (7)$$

where r represents the particular month or year.

The summations extend over the values for the n stations.

To simplify the computations involved in repeating the process thirteen times (twelve months and the year) the following method due to Fisher ([10]) was used. (For a fuller account of this method see Fisher's book, section 29).

By solving the three sets of simultaneous equations :

$$b_{r1} \Sigma \varphi^2 + b_{r2} \Sigma \varphi\lambda + b_{r3} \Sigma \varphi h = 1, 0, 0. \quad \cdots \quad (8)$$

$$b_{r1} \Sigma \varphi\lambda + b_{2} \Sigma \lambda^2 + b_{r3} \Sigma \lambda h = 0, 1\ 0. \quad \cdots \quad (9)$$

$${}_{r1} \Sigma \varphi h + b_{r2} \Sigma \lambda h + b_{r3} \Sigma h^2 = 0, 0, 1. \quad \cdots \quad (10)$$

we get at the matrix of multipliers :

$b_1 = m_{11},\ m_{12},\ m_{13}.$
$b_2 = m_{12},\ m_{22},\ m_{23}.$
$b_3 = m_{13},\ m_{23},\ m_{33}.$

The partial regression coefficients of normal mean temperature in any month* on latitude, longitude and altitude can be readily obtained as :

$$b_{r1} = m_{11} \Sigma \varphi t_r + m_{12} \Sigma \lambda t_r + m_{13} \Sigma h t_r \quad \cdots \quad (11)$$

$$b_{r2} = m_{12} \Sigma \varphi t_r + m_{22} \Sigma \lambda t_r + m_{23} \Sigma h t_r \quad \cdots \quad (12)$$

$$b_{r3} = m_{13} \Sigma \varphi t_r + m_{23} \Sigma \lambda t_r + m_{33} \Sigma h t_r \quad \cdots \quad (13)$$

The standard errors of the regression coefficients are obtained by determining the values of $s\sqrt{m_{11}}$, $s\sqrt{m_{22}}$ and $s\sqrt{m_{33}}$, where s, which is the residual standard error,

* In fact any element associated with the stations selected, e g., pressure, humidity, rainfall etc. can be treated in a similar manner.

is the square root of the sums of squares of differences of the calculated values from the observed values divided by the number of degrees of freedom remaining after fitting the formula. *i.e.*,

$$s=\left\{ \Sigma(t-t')^2/(n-4) \right\}^{\frac{1}{2}}$$

This can be readily seen to be equal to

$$\left[\left\{ \Sigma t^2 - b_1 \Sigma\varphi t - b_2 \Sigma\lambda t - b_3 \Sigma h t \right\}/(n-4)\right]^{\frac{1}{2}}$$

where, t and t′ represent the deviations of observed and calculated temperatures from the mean values.

The multiple correlation coefficient R is computed from :

$$R = \left\{ (b_1 \Sigma \varphi t + b_2 \Sigma\lambda t + b_3 \Sigma h t)/\Sigma t^2 \right\}^{\frac{1}{2}}$$

5. Discussion of results.—In the first place, the whole area having a range of latitude from 8°N to 36°N, longitude from 66°E to 95°E and height upto 11.500 ft. has been considered as one unit and the regression formulae expressing the mean temperature in terms of the latitude, longitude and altitude were evolved.

The matrix of multipliers used for evaluating the regression coefficients and their standard errors is given below :

$$10^{-8} \begin{vmatrix} 4\cdot419995 & -0\cdot229758 & -0\cdot252595 \\ -0\cdot229758 & 4\cdot431427 & 0\cdot243591 \\ -0\cdot252595 & 0\cdot243591 & 0\cdot154482 \end{vmatrix}$$

The regression coefficients thus calculated, their standard errors and the multiple correlation coefficients obtained for the various months and the year are given in *Table 3*.

The regression on altitude is highly significant* through out the year. Except in May in the case of latitude and in February, March and April in the case of longitude the coefficients are significant. The seasonal variations of the three regression coefficients and the multiple correlation coefficients are shown in *Fig. 2*. From *Fig. 2(d)* showing the seasonal variation of the multiple correlation coefficient, it is seen that the temperature distribution over India can be estimated with greater accuracy from the regression formula during the months October to February than during the rest of the year.

The regression on latitude has a simple seasonal variation. Temperature gradients towards north are negative and steep in winter. The steepness of the gradient decreases as the Sun ascends the ecliptic, *i.e.*, the region tends to be more uniformly heated. During the period June to September, the vastness of the land area, the Sun's meridian altitude and the length of the day all aid the heating of upper India while the southwest monsoon drenches and cools the southern areas more. Thus we see that during this period the temperature increases towards north.

The regression on longitude is negative throughout though very small. During the period May to July the effect is pronounced, indicating that western portions are more heated than the eastern.

It is seen from *Fig. 2(c)* that the regression on altitude is fairly of the same order throughout the year fluctuating slightly about an annual value of 3°·27F per 1000 ft. It can be seen how it compares with the lapse rate of temperature obtained in the free atmosphere (*viz.*, 3°F per 1000 ft.).

* If the regression coefficient is more than double the standard error it is considered to be significant. It can be seen that this criterion corresponds to P=·05.

6. Regional peculiarities.—The results so far discussed refer to the average conditions over the whole of India. Broadly India may be divided into two regions. The Indo-Gangetic plain bordered on the north by the great Himalayan range and its off-shoots, lies mainly in the temperate zone. Peninsular India lying between the Arabian sea and the Bay of Bengal is in the tropics. A further division of these two into East and West regions is suggested by the presence of the dry arid Thar desert in Northwest India, the fertile Gangetic plains of the Northeast, the Arabian sea and the Bay of Bengal on either side of the Peninsula. The country has, therefore, been divided into four regions by the tropic of Cancer and the 78th east meridian. The number of meteorological stations available in each of them is as follows :

Region I—42 stations in the western half of the peninsula,
Region II—40 stations in the eastern half of the peninsula,
Region III—45 stations in North-east India and
Region IV—40 stations in North-west India.

The computations have been repeated in all the four cases. The matrix of multipliers obtained for each region is given below :—

Region I.

$$10^{-8}\begin{vmatrix} 48\cdot659355 & 44\cdot055316 & 1\cdot026408 \\ 44\cdot055316 & 183\cdot194571 & -4\cdot647735 \\ 1\cdot026408 & -4\cdot647735 & 1\cdot060489 \end{vmatrix}$$

Region II.

$$10^{-8}\begin{vmatrix} 139\cdot382528 & -136\cdot001683 & -30\cdot149745 \\ -136\cdot001683 & 179\cdot166640 & 36\cdot413218 \\ -30\cdot149745 & 35\cdot413218 & 12\cdot052940 \end{vmatrix}$$

Region III.

$$10^{-8}\begin{vmatrix} 351\cdot641798 & 30\cdot030265 & -8\cdot422430 \\ 30\cdot030265 & 32\cdot663480 & 0\cdot677198 \\ -8\cdot422430 & 0\cdot677198 & 0\cdot951501 \end{vmatrix}$$

Region IV.

$$10^{-8}\begin{vmatrix} 86\cdot197149 & -8\cdot568009 & -2\cdot971527 \\ -8\cdot568009 & 67\cdot938229 & -0\cdot035352 \\ -2\cdot971527 & -0\cdot065352 & 0\cdot379607 \end{vmatrix}$$

The regression coefficients, their standard errors and the multiple correlation coefficients in each case have been tabulated in *Tables 4 to 7* and have been graphically represented in *Figs. 3 to 6.*

Region I.—In the winter months temperature decreases whereas during the rest of the year it increases with increase of latitude. There is an increase of temperature with longitude except in November and December when the value of b_2 is insignificant. The maximum horizontal temperature gradient towards east occurs during the summer. The regression on altitude is fairly uniform throughout the year with very slight fluctuations about the annual value of 3·18°F per 1000 ft. The multiple correlation coefficients range from 89 in March to ·97 in November.

Region II.—Temperature decreases towards north during November to February and increases during April to June. During the rest of the year the north to south gradients are weak or insignificant. Temperature gradients towards east are negative during January to June with steepest gradients in May and insignificant during the rest of the year. The regression on altitude fluctuates somewhat irregularly about an annual value of 3·28°F per 1000 ft.

The interesting feature of this region is that the multiple correlation coefficients even though significant at the 1% point in all the months are smaller in March, April and June than in the other months indicating that the deviation of the isothermal surfaces from the best fitting planes are greater during these months than during the rest of the year. The setting up of an inflow of winds from sea to land in the coastal districts and the location of the region of highest temperature over Central Deccan or slightly to the north of it during March and April account for the lower values of 'R' in these months. In May there is an improvement in the value of 'R' due to the fact that the region of highest temperature is shifted to the top left hand corner of the region and the coastal winds have got weaker in the process of their transformation into the southwest monsoon system of circulation. In June the heterogeneity is introduced by the onset of the southwest monsoon.

Region III.—Except in June when we obtain a multiple correlation coefficient of ·9, the multiple correlation coefficients in the other months are fairly high ranging from ·95 to ·99. The regression on latitude is negative except during the monsoon months (June to September) when they are insignificant. Gradients get steeper as summer advances and fall off from April towards June.

The regression coefficients on longitude are negative in all months except during November to January when they are insignificant. The variation of temperature with altitude is greatest in summer and least in winter though the monsoon slightly modifies the uniformity in the increase towards summer and the decrease towards winter. We get temperature gradients as low as 2°·1F per 1000 ft. in winter but the summer gradients range from 2°·9F to 3°·3F per 1000 ft.

Region IV.—The multiple correlation coefficients are fairly high throughout ranging from ·95 to 98. The regression on latitude is positive during the monsoon season (June to September). During the rest of the year the values are reversed in sign. The regression coefficients on longitude are negative during July to August, insignificant in June and September and positive during the rest of the year.

The curve for the regression coefficient on altitude retains in general the same characteristics as are shown by the curve for the whole of India (*Fig. 2(c)*). The temperature gradient is never less than 3°F per 1000 ft and attains a value of 4°·6F in the hot weather period. This can be contrasted with the temperature gradients obtained in Region III where it ranges from 2°·1 F to 3°·3F per 1000 ft.

7. Further examination of the variation of temperature with altitude.—Temperature gradients in the vertical are not the same at all heights. With a view to analyse the temperature gradients in different ranges of height the selected stations have been grouped according to height as follows :

Range No.	Height.	Number of stations.
I	Stations below 1000′ of elevation	109
II	Stations below 3000′ and above 1000′	33
III	Stations above 3000′	25

The regression coefficients have been calculated for annual temperature in each case.

The matrices used in the evaluation of the regression coefficients and their probable errors are given below :

Range I.

$$10^{-7}\begin{vmatrix} 0\cdot879341 & -0\cdot135526 & -0\cdot380420 \\ -0\cdot135526 & 0\cdot609537 & 0\cdot294074 \\ -0\cdot380420 & 0\cdot294074 & 1\cdot256132 \end{vmatrix}$$

Range II.

$$10^{-7}\begin{vmatrix} 3\cdot182328 & 0\cdot324985 & 0\cdot526966 \\ 0\cdot324985 & 10\cdot234195 & -0\cdot118157 \\ 0\cdot526966 & -0\cdot118157 & 1\cdot719198 \end{vmatrix}$$

Range III.

$$10^{-7}\begin{vmatrix} 1\cdot953080 & 0\cdot945366 & -0\cdot175667 \\ 0\cdot945366 & 5\cdot075352 & -0\cdot189156 \\ -0\cdot175667 & -0\cdot189156 & 0\cdot113782 \end{vmatrix}$$

The regression coefficients, their standard errors and the multiple correlation coefficients obtained in each case in regard to annual temperature are given in *Table VIII.*

In range III the multiple correlation coefficient is only ·54 which is not significant even at the 5% level but it must be noted that the number of stations considered is only 25, too small for drawing any definite conclusion. In this range, however, we notice that latitude and longitude have practically no effect and variation in temperature is mostly governed by the differences in height.

In range II, we obtain a multiple correlation coefficient of ·89. Temperature gradient in the vertical is greater in this than in range III. The effect of longitude is insignificant, but there is a significant decrease of temperature with latitude.

In the lowest of the height ranges, the regression on altitude is insignificant and it appears that latitude and longitude control the temperature more than the elevation.

8. Comparison of calculated temperatures with the observed ones.—With a view to see how far the mean temperatures calculated from the formulae* agree with the observed temperatures, the 'anomalies'** of temperature for the four typical months January, April, July and October were calculated and the iso-anomaly curves were drawn. (*Figs. 7 to 10*). It is interesting to note that the anomalies are fairly small, say, within a degree or two Fahrenheit, at most of the stations. They indicate the features, which contribute to the divergence and large deviations that occur are marked by orographical peculiarities.

9. Acknowledgments.—In conclusion, I wish to thank Dr. L. A. Ramdas for his many valuable suggestions, and the keen interest he has been taking in the preparation of this paper and for affording me the use of computing machines, without which I could not have completed the laborious calculations. My thanks are also due to Dr. S. K. Banerji for his kindness in reading through the manuscript, and at whose suggestions Section 8 was later added.

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* For this purpose, the co-efficients in *Tables IV, V, VI and VII* were used.

** Here we are using the term in the same sense which Ono and Nisimura (Ref. 7.) were using viz., Anomaly=Calculated – Observed. Madsen (Ref. 6.) uses the term 'Meteorological series' for the negative of the same.

Table I.

Latitude, Longitude and Altitude of 167 Meteorological Stations in India.

S. No.	Name of Station.	Latitude. N	Longitude. E	Height above mean sea level.
	REGION I.			Ft.
1	Bhuj	23° 15′	69° 48′	343
2	Dwaraka	22° 22′	69° 05′	37
3	Jamnagar	22° 29′	70° 04′	60
4	Rajkot	22° 18′	70° 50′	432
5	Veraval	20° 53′	70° 26′	19
6	Surat	21° 12′	72° 50′	39
7	Bhavnagar	21° 45′	72° 12′	55
8	Ahmedabad	23° 02′	72° 35′	163
9	Indore	22° 43′	75° 54′	1821
10	Akola	20° 42′	77° 02′	925
11	Amraoti	20° 56′	77° 47′	1213
12	Buldhana	20° 32′	76° 14′	2134
13	Khandwa	21° 50′	76° 22′	1044
14	Hoshangabad	22° 46′	77° 44′	992
15	Bombay	18° 54′	72° 49′	37
16	Ratnagiri	16° 59′	73° 18′	207
17	Marmugao	15° 25′	73° 47′	202
18	Karwar	14° 49′	74° 08′	44
19	Malegaon	20° 33′	74° 32′	1430
20	Ahmednagar	19° 05′	74° 55′	2154
21	Poona	18° 32′	73° 51′	1834
22	Sholapur	17° 40′	75° 54′	1570
23	Bijapur	16° 49′	75° 43′	1950
24	Belgaum	15° 51′	74° 31′	2562
25	Aurangabad	19° 53′	75° 20′	1905
26	Bidar	17° 55′	77° 32′	2165
27	Gulbarga	17° 21′	76° 51′	1503
28	Raichur	16° 12′	77° 21′	1311
29	Chitaldrug	14° 14′	76° 27′	2405

TABLE I—*contd.*

S. No.	Name of Station.	Latitude. N	Longitude. E	Height above mean sea level.
	REGION I—*contd.*			Ft.
30	Hassan	13° 00′	76° 09′	3149
31	Bangalore	12° 58′	77° 35′	3021
32	Mysore	12° 18′	76° 42′	2518
33	Mangalore	12° 52′	74° 51′	79
34	Calicut	11° 15′	75° 47′	27
35	Cochin	9° 58′	76° 14′	9
36	Trivandrum	8° 29′	76° 57′	200
37	Palamcottah	8° 44′	77° 45′	168
38	Coimbatore	11° 00′	76° 58′	1341
39	Bellary	15° 09′	76° 51′	1475
40	Mercara	12° 25′	75° 44′	3781
41	Ootacamund	11° 24′	76° 50′	7364
42	Kodaikanal	10° 14′	77° 28′	7688
	REGION II.			
1	Chittagong	22° 21′	91° 50′	87
2	Noakhali	22° 49′	91° 07′	22
3	Barisal	22° 42′	90° 22′	12
4	Jessore	23° 10′	89° 13′	26
5	Calcutta	22° 32′	88° 20′	22
6	Saugor Island	21° 39′	88° 03′	10
7	Midnapur	22° 25′	87° 19′	149
8	Burdwan	23° 14′	87° 51′	99
9	Bankura	23° 14′	87° 04′	313
10	Krishnagar	23° 24′	88° 31′	48
11	Balasore	21° 30′	86° 56′	65
12	Puri	19° 48′	85° 49′	20
13	Gopalpur	19° 16′	84° 53′	56
14	Cuttack	20° 29′	85° 52′	87
15	Sambalpur	21° 28′	83° 58′	48

TABLE I—*contd.*

S No.	Name of Station.	Latitude. N	Longitude. E	Height above mean sea level.
	REGION II—*contd.*			
				Ft.
16	Purulia	23° 20′	86° 25′	816
17	Ranchi	23° 23′	85° 2[illegible]	2152
18	Jubbalpore	23° 10′	79° 57′	1289
19	Seoni	22° 05′	79° 33′	2027
20	Nagpur	21° 09′	79° 07′	1017
21	Raipur	21° 14′	81° 39′	970
22	Chanda	19° 58′	79° 18′	634
23	Nizamabad	18° 40′	78° 06′	1250
24	Hyderabad	17° 22′	78° 27′	1719
25	Hanamkonda	18° 01′	79° 34′	877
26	Pamban	9° 16′	79° 18′	37
27	Madura	9° 55′	78° 07′	463
28	Negapatam	10° 46′	79° 51′	31
29	Trichinopoly	10° 49′	78° 42′	255
30	Salem	11° 39′	78° 1[illegible]	913
31	Cuddalore	11° 46′	79° 46′	39
32	Vellore	12° 55′	79° 09′	7[illegible]3
33	Madras	13° 04′	80° 15′	22
34	Cuddapah	14° 29′	78° 50′	428
35	Kurnool	15° 50′	78° 04′	923
36	Nellore	14° 27′	79° 59′	66
37	Masulipatam	16° 11′	81° 08′	10
38	Cocanada	16° 57′	82° 14′	26
39	Vizagapatam	17° 42′	83° 18′	126
40	Pachmarhi	22° 28′	78° 26′	35[illegible]
	REGION III.			
1	Dibrugarh	27° 28′	94° 55′	348
2	Sibsagar	26° 59′	94° 38′	317
3	Tezpur	26° 37′	92° 47′	258
4	Dhubri	26° 01′	89° 59′	115

TABLE I—*contd.*

S. No.	Name of Station.	Latitude. N	Longitude. E	Height above mean sea level.
	REGION III—*contd.*			Ft.
5	Silchar	24° 49′	92° 48′	96
6	Comilla	23° 28′	91° 11′	366
7	Narayanganj	23° 37′	90° 30′	26
8	Bogra	24° 51′	89° 23′	63
9	Mymensingh	24° 46′	90° 24′	62
10	Rampur Boalia	24° 22′	88° 36′	70
11	Faridpur	23° 37′	89° 51′	27
12	Berhampore	24° 08′	88° 16′	62
13	Malda	25° 02′	88° 08′	108
14	Sirajganj	24° 27′	89° 45′	49
15	Dinajpur	25° 38′	88° 38′	123
16	Rangpur	25° 45′	89° 15′	123
17	Jalpaiguri	26° 32′	88° 43′	271
18	Hazaribagh	23° 59′	85° 22′	2006
19	Daltonganj	24° 03′	84° 04′	725
20	Purnea	25° 46′	87° 28′	124
21	Bhagalpur	25° 15′	87° 02′	160
22	Dharbanga	26° 10′	85° 54′	162
23	Motihari	26° 40′	84° 55′	220
24	Chapra	25° 47′	84° 44′	181
25	Patna	25° 37′	85° 10′	173
26	Gaya	24° 49′	85° 01′	372
27	Naya Dumka	24° 16′	87° 15′	489
28	Gorakhpur	26° 45′	83° 22′	257
29	Benares	25° 18′	83° 01′	250
30	Allahabad	25° 26′	81° 50′	309
31	Cawnpore	26° 28′	80° 21′	416
32	Lucknow	26° 52′	80° 56′	368
33	Bahraich	27° 34′	81° 36′	407

TABLE I—*contd.*

S. No.	Name of Station.	Latitude. N	Longitude. E	Height above mean sea level.
	REGION III—*concld.*			
				Ft.
34	Jhansi	25° 27′	78° 35′	834
35	Agra	27° 08′	78° 01′	554
36	Mainpuri	27° 14′	79° 03′	516
37	Bareilly	28° 22′	79° 24′	568
38	Dehra Dun	30° 19′	78° 02′	2239
39	Nowgong	25° 04′	79° 27′	750
40	Sutna	24° 34′	80° 50′	1041
41	Saugor	23° 51′	78° 45′	1808
42	Darjeeling	27° 03′	88° 16′	7432
43	Katmandu	27° 42′	85° 12′	4388
44	Mukteswar	29° 28′	79° 39′	7592
45	Ranikhet	29° 38′	79° 29′	6070
	REGION IV.			
1	Meerut	29° 01′	77° 43′	733
2	Roorkee	29° 51′	77° 53′	899
3	Delhi	28° 39′	77° 15′	714
4	Sirsa	29° 32′	75° 01′	662
5	Patiala	30° 20′	76° 28′	813
6	Ambala	30° 23′	76° 46′	892
7	Ludhiana	30° 56′	75° 52′	812
8	Lahore	31° 35′	74° 20′	702
9	Sialkot	32° 30′	74° 32′	830
10	Rawalpindi	33° 36′	73° 07′	1674
11	Khushab	32° 18′	72° 22′	612
12	Montgomery	30° 39′	73° 08′	558
13	Multan	30° 12′	71° 31′	413

TABLE I—*concld.*

S. No.	Name of station.	Latitude. N	Longitude. E	Height above mean sea level.
	REGION IV—*contd.*			Ft.
14	Srinagar	34° 05′	74° 50′	5205
15	Dras	34° 26′	75° 46′	10059
16	Leh	34° 09′	77° 34′	1500
17	Skardu	35° 18′	75° 37′	7505
18	Gilgit	35° 55′	74° 23′	4890
19	Peshawar	34° 01′	71° 35′	1164
20	Dera Ismail Khan	31° 49′	70° 55′	570
21	Quetta	30° 10′	67° 01′	5540
22	Kalat	29° 02′	66° 35′	6616
23	Pishin	30° 35′	66° 59′	5150
24	Jacobabad	28° 17′	68° 29′	186
25	Hyderabad (Sind)	25° 23′	68° 25′	96
26	Manora	24° 48′	66° 59′	13
27	Bikaner	28° 00′	73° 18′	762
28	Jodhpur	26° 18′	73° 01′	780
29	Jaipur	26° 55′	75° 50′	1431
30	Ajmer	26° 27′	74° 37′	1593
31	Kotah	25° 11′	75° 51′	843
32	Deesa	24° 14′	72° 12′	466
33	Neemuch	24° 28′	74° 54′	1626
34	Simla	31° 06′	77° 10′	7224
35	Chakrata	30° 43′	77° 54′	6922
36	Murree	33° 55′	73° 23′	7082
37	Cherat	33° 50′	71° 54′	4272
38	Parachinar	33° 52′	70° 04′	5673
39	Drosh	35° 34′	71° 47′	4723
40	Mount Abu	24° 36′	72° 43′	3945

TABLE II.

Normal Mean Temperature in tenths of degrees Fahrenheit of 167 Meteorological stations in India.

Name of Station.	Jan	Feb	March.	Apl	May.	Jun.	Jul	Aug	Sep	Oct	Nov.	Dec	Year.
					REGION I.								
1. Bhuj ..	668	704	789	856	889	887	846	824	834	833	760	684	798
2. Dwaraka ..	692	707	762	805	842	857	838	815	816	816	777	710	787
3. Jamnagar ..	666	691	767	827	872	880	849	824	823	822	761	683	788
4. Rajkot ..	674	703	784	855	901	888	837	817	820	820	755	689	795
5. Veraval ..	707	711	752	791	824	837	818	802	800	808	783	732	781
6. Surat ..	721	744	812	864	880	864	826	817	822	826	779	732	807
7. Bhavnagar ..	695	724	805	878	916	899	860	841	841	833	771	706	814
8. Ahmedabad ..	713	737	821	894	933	911	858	834	845	849	792	729	826
9. Indore ..	649	677	764	849	895	855	791	770	778	762	694	649	761
10. Akola ..	700	740	823	902	945	884	820	804	812	795	731	684	803
11. Amraoti .	717	757	834	904	939	876	809	795	803	799	746	703	807
12. Buldhana ..	700	739	814	880	895	831	775	758	764	773	725	690	779
13. Khandwa ..	685	722	810	897	939	886	818	799	807	793	722	674	796
14. Hoshangabad	661	701	794	886	937	894	816	795	803	781	708	656	[illegible]
15. Bombay ..	748	751	787	821	851	834	810	804	804	821	808	775	801
16. Ratnagiri ..	770	765	796	832	853	820	800	796	794	812	806	784	802
17. Mormugao .	772	778	807	841	855	821	799	796	793	805	796	777	803
18. Karwar ..	762	765	798	834	847	807	791	787	785	796	787	770	794
19. Malegaon ..	692	725	803	873	900	856	809	795	795	795	728	685	786
20. Ahmednagar	686	720	787	846	866	820	781	769	771	773	719	681	768
21. Poona ..	702	734	800	850	858	811	769	757	766	778	731	693	771
22. Sholapur ..	733	777	844	897	906	843	807	799	797	797	753	719	806
23. Bijapur ..	731	775	836	877	877	818	788	782	784	787	741	711	792
24. Belgaum ..	707	739	787	816	807	748	717	714	724	743	720	701	744
25. Aurangabad .	704	738	810	874	894	835	787	772	778	786	734	696	784
26. Bidar ..	720	764	828	871	889	825	773	758	761	771	733	709	784
27. Gulbarga ..	735	783	850	900	914	849	808	800	800	801	755	720	81[illegible]
28. Raichur .	756	803	862	909	913	852	817	811	807	813	773	743	821
29. Chitaldrug ..	732	776	824	848	830	782	755	753	758	764	737	717	77[illegible]
30. Hassan ..	690	725	768	795	780	733	715	717	726	730	704	682	73[illegible]
31. Bangalore ..	692	732	780	815	805	759	741	739	740	737	710	687	7[illegible]
32. Mysore ..	721	762	805	825	808	763	748	750	754	756	734	711	76[illegible]
33. Mangalore ..	796	803	824	851	849	799	791	788	792	802	805	797	8[illegible]

TABLE II—*contd.*

Name of Station.	Jan.	Feb.	Mar.	Apl.	May	Jun	Jul.	Aug	Sep.	Oct.	Nov.	Dec.	Year.
					REGION I—*contd.*								
34. Calicut ..	789	805	829	846	841	798	781	785	792	803	802	790	805
35. Cochin ..	807	821	843	851	837	801	791	793	798	807	811	808	814
36. Trivandrum .	782	797	821	831	823	794	785	787	791	790	785	781	797
37. Palamcottah ..	798	826	863	885	906	883	871	877	879	848	814	793	854
38. Coimbatore .	754	788	830	854	842	806	792	795	800	793	774	752	798
39. Bellary ..	750	801	863	904	900	854	831	824	818	808	769	738	821
40. Mercara ..	670	699	729	738	722	677	655	656	668	688	678	664	687
41. Ootacamund	543	557	589	616	613	583	571	573	578	576	558	546	576
42. Kodaikanal ..	553	569	599	619	620	595	579	579	580	572	553	550	581
					REGION II								
1. Chittagong ..	668	705	771	808	821	818	813	811	816	800	744	678	771
2. Noakhali ..	657	694	771	811	825	821	818	815	821	801	737	665	770
3. Barisal .	663	706	789	830	841	833	830	826	830	810	741	668	781
4. Jessore ..	652	697	794	854	854	847	840	[illegible]	[illegible]	814	[illegible]	659	785
5. Calcutta ..	666	713	802	856	861	851	837	832	832	810	735	665	788
6. Saugor Island	679	728	807	847	860	855	841	835	838	817	746	677	794
7. Midnapur ..	684	733	820	883	889	861	845	839	838	814	741	675	802
8. Burdwan ..	669	710	805	874	875	860	847	841	842	817	740	671	796
9. Bankura .	668	710	808	890	898	878	843	836	836	810	733	664	798
10. Krishnagar ..	649	689	789	864	866	856	843	841	839	811	731	656	786
11. Balasore ..	685	731	808	862	876	857	839	834	834	810	736	676	796
12. Puri ..	719	762	809	832	854	848	838	837	843	832	771	714	805
13. Gopalpur ..	713	754	800	825	851	850	835	833	825	814	755	705	797
14. Cuttack .	717	770	845	890	906	875	843	838	841	[illegible]	756	699	817
15. Sambalpur ..	684	733	815	892	937	888	825	820	829	802	728	667	804
16. Purulia ..	662	703	796	880	895	869	840	830	828	800	725	657	791
17. Ranchi ..	627	662	753	838	869	832	791	782	781	750	679	620	749
18. Jubbulpore ..	631	670	762	855	919	884	809	[illegible]	800	760	676	619	765
19. Seoni ..	652	691	774	853	898	850	783	771	777	755	685	640	761
20. Nagpur ..	696	741	823	903	952	890	817	807	815	795	728	680	804
21. Raipur ..	685	732	817	897	942	881	810	803	815	791	722	668	797
22. Chanda ..	702	752	831	910	956	844	823	813	817	792	723	675	807
23. Nizamabad ..	713	762	833	900	937	871	813	797	801	789	731	688	803
24. Hyderabad ..	721	770	834	887	916	853	805	792	794	789	739	704	809

TABLE II—*contd.*

Name of Station.	Jan.	Feb.	Mar.	Apl	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year.
					REGION II—*contd.*								
25. Hanamkonda ..	740	782	845	895	934	885	827	816	818	808	758	722	819
26 Pamban .	785	798	827	853	862	851	843	839	839	827	806	786	826
27. Madura .	783	810	848	881	890	876	867	861	852	827	801	782	840
28. Negapatam ..	770	789	825	861	891	886	872	858	847	825	795	771	832
29. Trichinopoly	776	807	853	895	902	888	876	868	855	828	797	774	843
30. Salem ..	764	800	848	886	880	850	833	826	820	807	786	[illegible]	821
31. Cuddalore ..	757	777	808	853	894	894	870	855	843	813	787	764	827
32. Vellore ..	742	778	823	877	903	882	857	849	837	811	769	[illegible]	822
33. Madras ..	762	778	811	853	899	901	874	860	852	823	789	767	831
34 Cuddapah .	768	820	882	931	945	902	820	859	848	834	791	759	851
35. Kurnool ..	744	796	861	914	928	872	834	823	819	812	768	734	825
36. Nellore .	762	796	838	886	931	917	885	874	862	835	788	760	845
37. Masulipatam	746	776	817	861	906	893	855	846	842	825	783	748	825
38. Cocanada ..	737	778	829	873	905	834	848	840	842	821	772	734	822
39. Vizagapatam	744	775	810	840	864	857	838	835	833	822	785	745	812
40. Pachmarhi ..	597	631	720	807	853	798	725	709	719	693	626	583	705
					REGION III.								
1. Dibrugarh ..	606	635	692	725	776	806	811	814	806	770	699	622	730
2. Sibsagar ..	599	630	662	736	[illegible]	824	885	831	819	774	687	610	735
3. Tezpur ..	630	659	722	753	796	827	834	834	826	[illegible]	710	640	751
4. Dhubri ..	635	668	744	787	797	811	[illegible]	823	814	786	718	647	704
5. Silchar ..	652	651	745	783	807	627	836	832	[illegible]	805	704	[illegible]	768
6. Comilla ..	658	696	781	823	829	825	822	820	825	805	738	666	774
7. Narayanganj	666	702	787	830	835	835	836	833	836	816	748	676	784
8. Bogra ..	640	674	766	833	833	833	837	835	832	801	723	652	772
9. Mymensingh	648	678	760	809	818	823	829	829	828	804	737	662	769
10 Rampur Boalia	636	672	[illegible]	848	849	845	838	835	833	804	721	649	775
11. Faridpur ..	642	678	773	830	832	833	831	829	830	803	729	653	772
12. Berhampore	651	690	757	[illegible]	865	853	843	838	838	811	732	659	786
13. Malda ..	627	664	757	840	856	853	844	843	837	802	716	639	773
14. Sirajganj ..	639	670	766	831	823	827	831	828	828	[illegible]	725	653	768
15. Dinajpur ..	625	660	748	818	829	838	840	838	832	797	716	641	765
16. Rangpur ..	622	650	736	803	810	824	838	835	826	795	715	608	768
17. Jalpaiguri ..	624	650	723	786	808	822	828	829	818	785	714	644	753

TABLE II—*contd.*

Name of Station.	Jan.	Feb.	Mar.	Apl.	May	Jun.	Jul.	Aug.	Sep.	Oct	Nov.	Dec.	Year.
					REGION III—*contd.*								
18. Hazaribagh ..	620	658	757	850	876	846	796	787	783	753	678	614	752
19. Daltonganj ..	613	657	750	853	925	902	849	830	827	778	686	611	774
20. Purnea ..	613	652	747	829	846	845	843	838	832	794	705	626	764
21. Bhagalpur .	625	665	769	851	870	850	847	840	835	799	711	633	775
22. Dharbanga ..	619	651	747	833	853	856	845	840	836	799	713	635	769
23 Motihari ..	598	630	732	824	857	856	842	837	833	785	691	612	758
24. Chapra ..	616	653	762	858	890	882	855	843	841	800	709	628	778
25. Patna ..	618	659	767	862	887	878	852	843	842	806	714	630	780
26. Gaya ..	636	683	790	887	921	899	855	843	843	806	715	637	793
27. Naya Dumka	635	680	779	866	879	857	837	830	828	794	711	636	778
28 Gorakhpur ..	608	648	756	805	886	880	850	840	838	792	697	619	772
29 Benares ..	611	657	765	868	[illegible]	911	860	842	840	792	692	614	781
30 Allahabad ..	612	657	768	874	931	924	863	843	842	793	694	617	785
31. Cawnpore ..	605	648	752	863	926	925	871	848	844	792	643	614	782
32. Lucknow ..	604	647	755	861	913	915	860	846	841	788	686	611	777
33. Bahraich .	[illegible]	635	754	839	893	889	856	843	838	794	698	613	769
34. Jhansi ..	635	680	790	896	960	942	860	834	839	814	720	647	801
35. Agra ..	608	651	761	870	939	946	830	857	854	809	705	622	792
36. Mainpuri ..	594	634	739	851	936	932	879	853	844	792	691	608	779
37. Bareilly .	583	624	728	835	896	901	856	842	833	775	674	593	761
38. Dehra Dun ..	554	579	670	768	829	841	799	784	773	717	637	572	710
39. Nowgong ..	607	652	759	864	934	926	847	825	824	777	676	607	775
40. Sutna ..	615	657	759	861	924	908	831	811	813	771	679	612	770
41 Saugor .	647	680	778	867	919	883	801	782	790	774	702	648	772
42. Darjeeling .	412	425	494	555	585	614	624	621	607	559	492	431	535
43. Katmandu	512	540	616	683	725	759	766	761	747	682	596	525	659
44. Mukteswar .	432	431	508	591	642	655	640	630	616	579	511	460	558
45. Ranikhet ..	467	477	568	656	696	709	687	674	662	617	549	501	[illegible]
					REGION IV.								
1. Meerut	575	612	716	825	893	910	865	847	832	766	663	588	758
2. Roorkee .	564	599	698	807	880	898	852	837	819	749	649	573	743
3. Delhi ..	590	632	738	854	921	935	880	861	851	800	695	609	831
4. Sirsa ..	566	607	717	835	921	902	912	894	870	797	675	586	778
5. Patiala ..	561	598	700	802	891	914	876	858	839	771	664	577	754

TABLE II—*concld.*

Name of Station.	Jan.	Feb.	Mar.	Apl	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year.
				REGION IV—*contd.*									
6. Ambala ..	560	599	697	806	895	915	873	855	836	768	659	576	753
7. Ludhiana ..	556	593	700	812	898	930	889	870	848	778	662	574	759
8. Lahore ..	550	586	690	802	893	938	907	885	859	777	658	567	759
9 Sialkot ..	544	576	675	790	884	929	888	864	844	770	652	558	748
10 Rawalpindi ..	504	532	627	727	831	897	874	847	813	727	609	521	709
11. Khushab ..	548	586	684	797	903	949	926	903	875	787	666	567	766
12. Montgomery	551	593	699	814	920	963	939	915	879	796	678	574	777
13. Multan ..	570	610	720	830	925	965	944	917	891	808	691	592	783
14 Srinagar ..	339	362	462	554	638	707	751	743	669	558	461	375	552
15. Dras ..	33	56	173	260	461	573	629	633	547	419	272	123	352
16. Leh ..	[illegible]	214	327	429	504	583	635	631	559	447	339	243	425
17. Skardu ..	249	284	412	522	613	689	713	746	660	538	417	310	516
18. Gilgit ..	392	495	534	625	720	801	843	833	755	640	524	415	627
19. Peshawar ..	513	543	632	728	843	920	917	938	833	733	614	528	724
20. Dera Ismail Khan ..	546	581	685	790	893	947	930	910	875	775	652	562	762
21 Quetta ..	399	421	512	597	679	748	790	766	677	571	489	424	589
22 Kalat ..	368	389	476	556	640	705	744	715	631	532	465	393	551
23. Pishin ..	386	417	504	594	698	770	808	781	633	572	489	411	593
24 Jacobabad ..	585	635	752	850	954	994	968	934	901	814	697	602	807
25. Hyderabad (Sind).	630	675	781	868	926	931	902	874	867	840	739	654	803
26 Manora ..	671	694	747	793	838	866	847	818	811	806	758	687	778
27. Bikaner ..	600	612	739	879	949	963	922	893	884	837	720	624	805
28. Jodhpur ..	637	670	768	864	929	930	889	854	852	821	737	659	801
29. Jaipur ..	614	649	748	851	921	926	837	839	838	798	707	630	782
30. Ajmer ..	597	636	743	849	918	912	850	820	824	783	683	611	769
31 Kotah ..	646	687	793	892	967	903	826	844	848	828	736	660	811
32. Deesa ..	675	704	795	875	922	914	806	827	838	822	751	691	806
33. Neemuch ..	632	662	760	853	904	880	813	789	796	778	699	638	767
34. Simla ..	412	414	493	578	651	669	646	630	612	570	504	446	532
35. Chakrata ..	436	438	519	602	604	671	651	642	631	590	523	473	569
36. Murree ..	407	408	492	584	676	729	696	674	658	610	528	451	576
37. Cherat ..	444	463	536	638	766	834	804	780	750	676	576	482	646
38. Parachinar ..	398	412	487	572	677	759	767	750	699	617	522	433	591
39. Drosh ..	398	415	489	590	707	803	848	839	767	651	542	432	623
40. Mount Abu ..	587	605	689	764	793	760	707	683	700	718	659	606	689

Table III.

Partial Regression Coefficients of normal mean temperature on Latitude, Longitude and Altitude of 167 meteorological stations in India.

	Partial regression coefficients of temperature on			Multiple correlation coefficients. R.
	Latitude.	Longitude.	Altitude.	
January ..	—·1914 ± ·0063	—·0141 ± ·0063	—·0310 ± ·0012	·97
February ..	—·1855 ± ·0069	—·0088 ± ·0069	—·0330 ± ·0013	·96
March ..	—·1316 ± ·0077	—·0043 ± ·0078	—·0351 ± ·0014	·94
April	—·0693 ± ·0110	—·0196 ± ·0110	—·0374 ± ·0021	·89
May	—·0022 ± ·0097	—·0565 ± ·0097	—·0378 ± ·0018	·87
June	+·0644 ± ·0078	—·0676 ± ·0078	—·0348 ± ·0015	·88
July	+·0708 ± ·0060	—·0366 ± ·0060	—·0294 ± ·0011	·90
August ..	+·0596 ± ·0054	—·0252 ± ·0054	—·0282 ± ·0010	·92
September ..	+·0324 ± ·0044	—·0116 ± ·0044	—·0315 ± ·0008	·95
October ..	—·0278 ± ·0040	—·0103 ± ·0040	—·0336 ± ·0007	·97
November ..	—·1028 ± ·0046	—·0129 ± ·0046	—·0312 ± ·0009	·97
December ..	—·1667 ± ·0055	—·0188 ± ·0055	—·0291 ± ·0010	·97
Annual ..	—·0542 ± ·0113	—·0262 ± ·0114	—·0327 ± ·0021	·82

Table IV.

Partial Regression Coefficients of normal mean temperature on Latitude, Longitude and Altitude of 42 stations in Region I.

	Partial regression coefficients of temperature on			Multiple correlation coefficients. R.
	Latitude.	Longitude.	Altitude.	
January ..	—·1019 ± ·0137	+·0954 ± ·0268	—·0322 ± ·0020	·94
February ..	—·0703 ± ·0174	+·1673 ± ·0339	—·0315 ± ·0026	·90
March ..	+·0176 ± ·0185	+·2309 ± ·0363	—·0311 ± ·0027	·89
April	+·1104 ± ·0179	+·2061 ± ·0351	—·0315 ± ·0026	·92
May	+·1739 ± ·0149	+·3042 ± ·0291	—·0333 ± ·0022	·96
June	+·1508 ± ·0146	+·1645 ± ·0285	—·0326 ± ·0022	·96
July	+·0721 ± ·0150	+·0768 ± ·0293	—·0324 ± ·0022	·94
August ..	+·0403 ± ·0145	+·0779 ± ·0284	—·0325 ± ·0021	·94
September ..	+·0442 ± ·0136	+·0831 ± ·0266	—·0321 ± ·0020	·95
October ..	+·0298 ± ·0109	+·0431 ± ·0214	—·0316 ± ·0016	·96
November ..	—·0567 ± ·0099	—·0096 ± ·0193	—·0330 ± ·0015	·97
December ..	—·1123 ± ·0123	+·0200 ± ·0241	—·0326 ± ·0018	·95
Annual ..	+·0243 ± ·0112	+·1276 ± ·0218	—·0318 ± ·0016	·96

Table V.

Partial Regression Coefficients of normal mean temperature on Latitude. Longiiude and Altitude of 40 stations in Region II.

	Partial regression coefficients of temperature on			Multiple correlation coefficients. R.
	Latitude.	Longitude.	Altitude.	
January ..	—·1048 ± ·0157	—·0690 ± ·0178	—·0296 ± ·0046	·97
February ..	—·0622 ± ·0262	—·0959 ± ·0298	—·0351 ± ·0077	·88
March ..	+·0135 ± ·0238	—·1035 ± ·0270	—·0324 ± ·0070	·78
April	+·0899 ± ·0265	—·1572 ± ·0301	—·0303 ± ·0078	·69
May	+·1447 ± ·0296	—·2370 ± ·0234	—·0366 ± ·0061	·88
June	+·0514 ± ·0208	—·1184 ± ·0236	—·0309 ± ·0061	·74
July	—·0265 ± ·0151	—·0191 ± ·0172	—·0319 ± ·0045	·90
August ..	—·0295 ± ·0135	—·0132 ± ·0153	—·0342 ± ·0040	·93
September ..	—·0069 ± ·0097	—·0208 ± ·0110	—·0340 ± ·0028	·95
October ..	—·0148 ± ·0103	—·0195 ± ·0118	—·0339 ± ·0030	·95
November ..	—·0945 ± ·0122	+·0010 ± ·0134	—·0290 ± ·0036	·97
December ..	—·1402 ± ·0183	—·0077 ± ·0208	—·0269 ± ·0054	·96
Annual ..	—·0127 ± ·0122	—·0762 ± ·0139	—·0328 ± ·0036	·94

Table VI.

Partial Regression Coefficients of normal mean temperature on Latitude, Longitude and Altitude of 45 stations in Region III.

	Partial regression coefficients of temperature one.			Multiple correlation coefficients. R.
	Latitude.	Longitude.	Altitude.	
January ..	—·1825 ± ·0256	—·0035 ± ·0078	—·0221 ± ·0013	·97
February ..	—·2157 ± ·0236	—·0194 ± ·0072	—·0259 ± ·0012	·98
March ..	—·2675 ± ·0213	—·0661 ± ·0045	—·0288 ± ·0011	·99
April	—·2991 ± ·0256	—·1461 ± ·0078	—·0310 ± ·0013	·98
May	—·2109 ± ·0323	—·1987 ± ·0098	—·0333 ± ·0017	·98
June	—·0711 ± ·0619	—·1787 ± ·0089	—·0326 ± ·0032	·90
July	+·0320 ± ·0278	—·0364 ± ·0085	—·0298 ± ·0014	·96
August ..	+·0310 ± ·0174	—·0251 ± ·0053	—·0295 ± ·0009	·98
September ..	—·0137 ± ·0163	—·0330 ± ·0050	—·0301 ± ·0009	·99
October ..	—·0827 ± ·0165	—·0223 ± ·0050	—·0293 ± ·0009	·99
November ..	—·1087 ± ·0288	+·0119 ± ·0088	—·0247 ± ·0015	·96
December ..	—·1312 ± ·0304	+·0055 ± ·0093	—·0212 ± ·0016	·95
Annual ..	—·1422 ± ·0264	—·0662 ± ·0080	—·0277 ± ·0014	·97

Table VII.

Partial Regression Coefficients of normal mean temperature on Latitude, Longitude and Altitude of 40 stations in Region IV.

	Partial regression coefficients of temperature on			Multiple correlation coefficients. R.
	Latitude.	Longitude.	Altitude.	
January ..	—·2388±·0392	+·0278±·0348	—·0324±·0026	·95
February ..	—·2192±·0378	+·0315±·0336	—·0354±·0025	·96
March ..	—·2275±·0307	+·0583±·0273	—·0361±·0020	·97
April	—·1901±·0333	+·0916±·0296	—·0390±·0022	·97
May	—·0795±·0290	+·0581±·0258	—·0405±·0019	·98
June	+·0697±·0246	—·0086±·0219	—·0381±·0016	·97
July	+·1675±·0267	—·0816±·0237	—·0320±·0018	·95
August ..	+·1745±·0263	—·0617±·0233	—·0313±·0017	·95
September ..	+·0718±·0238	+·0210±·0211	—·0345±·0016	·97
October ..	—·0800±·0251	+·0451±·0223	—·0338±·0017	·97
November ..	—·1634±·0282	+·0257±·0250	—·0300±·0019	·97
December ..	—·2273±·0348	+·0295±·0309	—·0287±·0023	·96
Annual ..	—·0861±·0227	+·0297±·0201	—·0341±·0015	·98

Table VIII.

Partial Regression Coefficients of normal mean temperature on Latitude, Longitude and Altitude for the different ranges of height.

Range No.	Partial regression coefficients of temperature on			Multiple correlation coefficients. Rs.
	Latitude.	Longitude.	Altitude.	
I	—·0570±·0052	—·0196±·0043	·0062±·0062	·79
II	—·0701±·0077	·0055±·0138	—·0391±·0056	·89
III	—·0370±·0630	—·0202±·1014	—·0366±·0152	·54**

**Insignificant at 5% level.

Dn:50DGofob—500—22-3-48—GIBPS

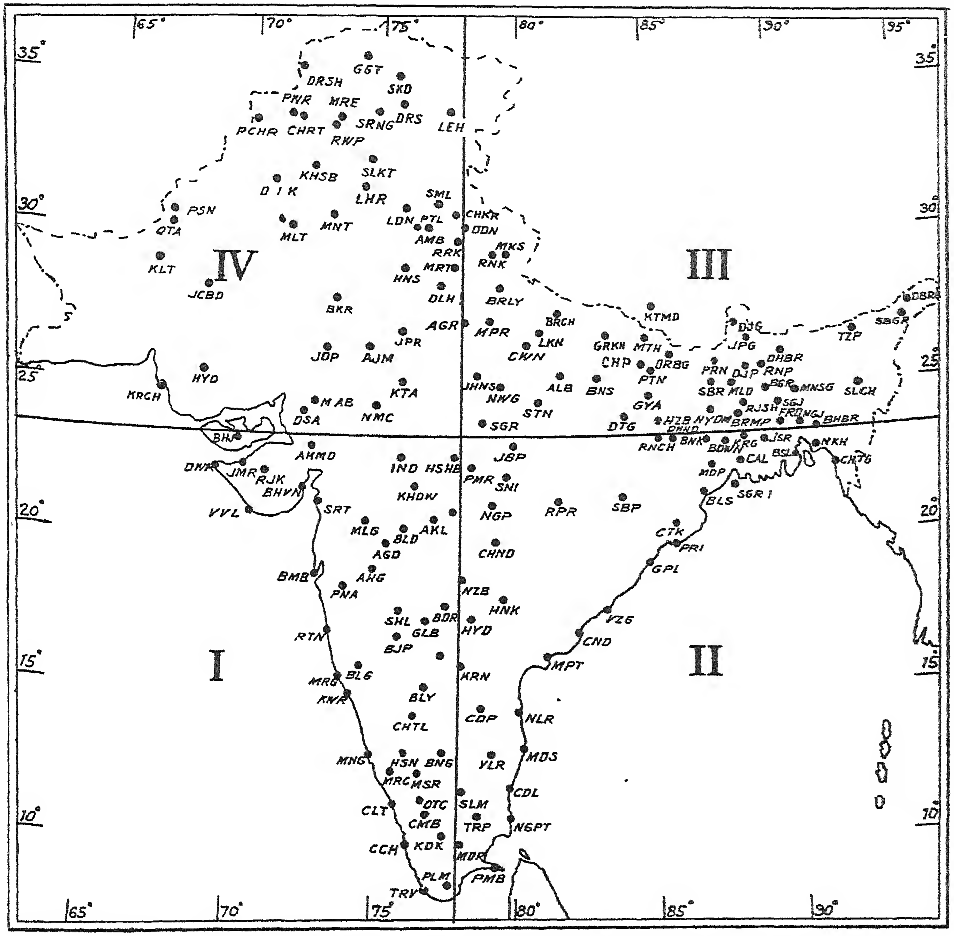

FIG. 1. 167 MET. STATIONS & THE FOUR DIVISIONS.

G P Z P POONA '47

MONTHLY VARIATION OF THE MULTIPLE CORRELATION COEFFICIENT (R) AND OF THE REGRESSION COEFFICIENTS ON LAT. (Φ) LONG. (λ) AND ALTITUDE (H)

Plate II

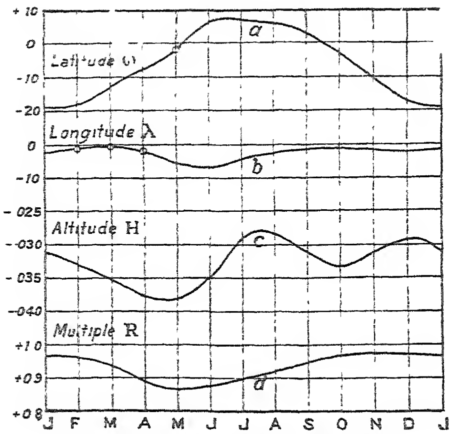

FIG. 2. FOR THE WHOLE OF INDIA.

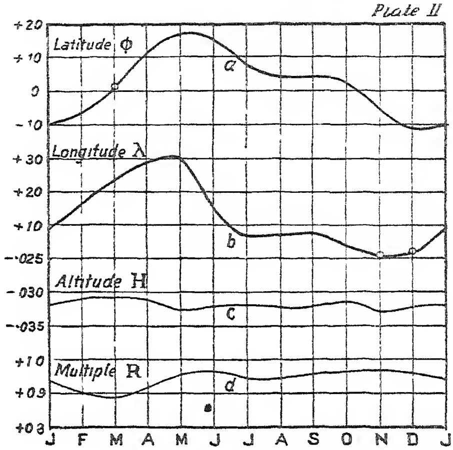

FIG. 3. FOR REGION I

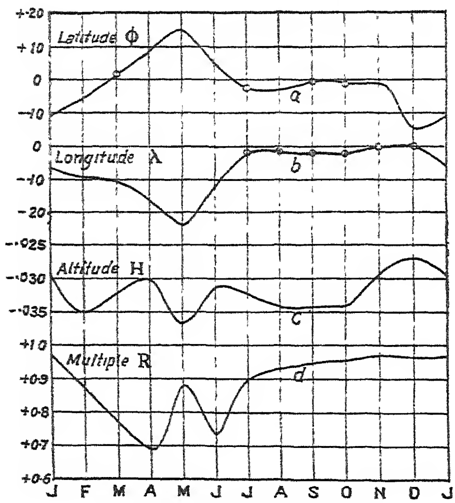

FIG. 4. FOR REGION II.

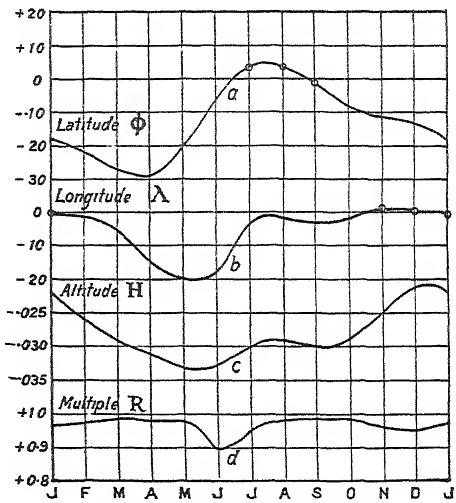

FIG. 5 FOR REGION III.

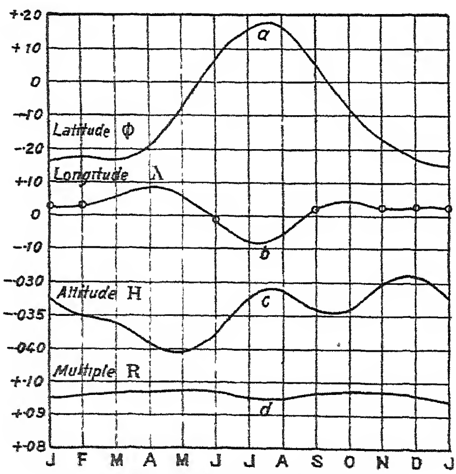

FIG. 6. FOR REGION IV.

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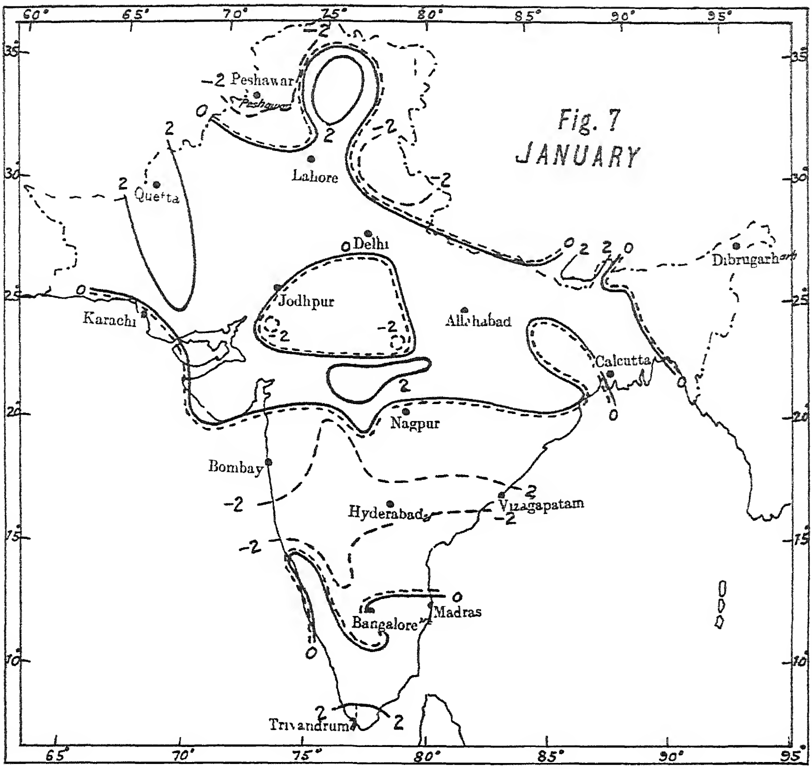
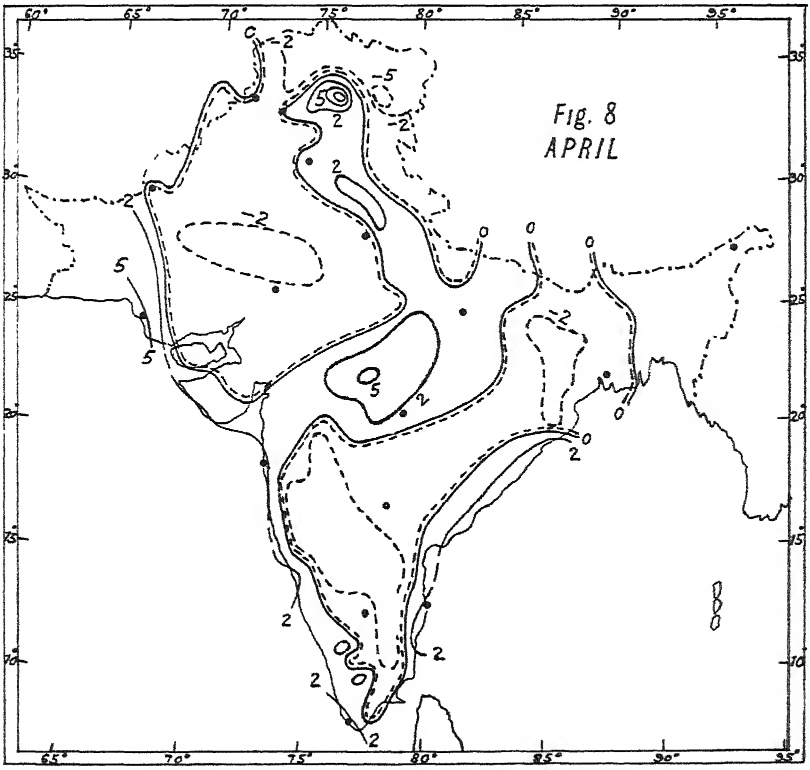
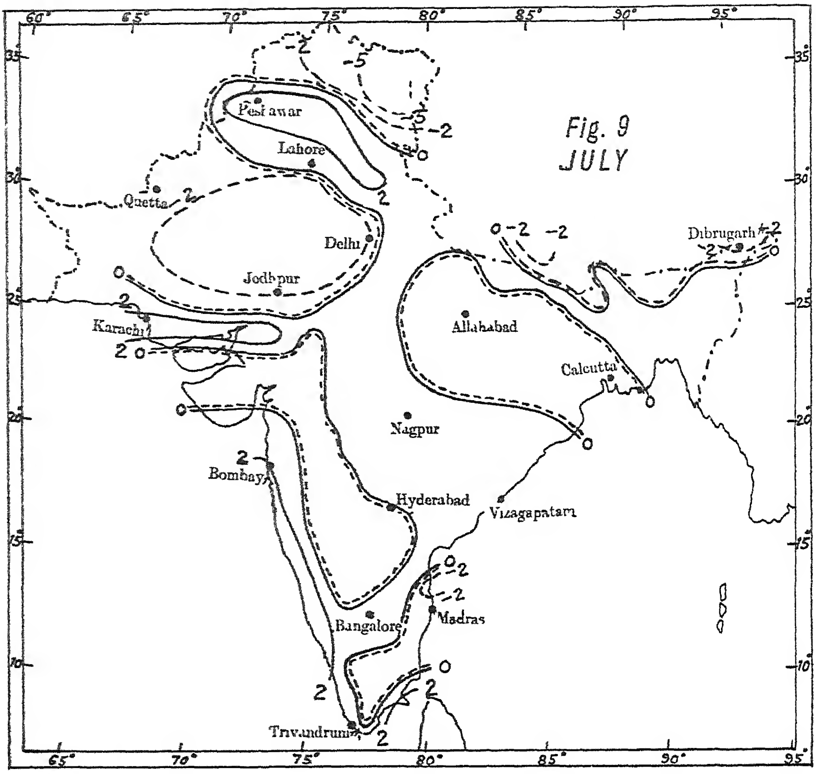
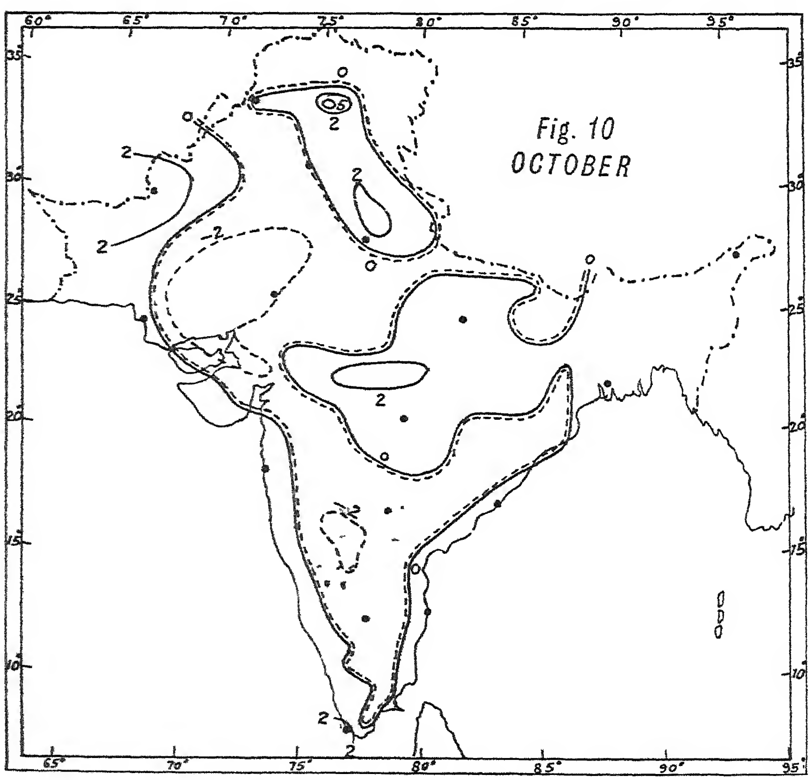




ANOMALIES OF AIR TEMPERATURE

G.P.Z.P. POONA. 1947





ANOMALIES OF AIR TEMPERATURE

G P Z R POONA 1947.

INDIA METEOROLOGICAL DEPARTMENT

SCIENTIFIC NOTES

Vol. X No. 122

Regression of Climatic Elements on Latitude, Longitude and Elevation in India

PART II—DIURNAL RANGE OF TEMPERATURE

BY

P. JAGANNATHAN

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REGRESSION OF CLIMATIC ELEMENTS ON LATITUDE, LONGITUDE AND ELEVATION IN INDIA.

PART II—DIURNAL RANGE OF TEMPERATURE.

BY

P. JAGANNATHAN

(*Received on 11th February 1946.*)

Abstract.—In this paper, the distribution of the daily range of temperature over India has been studied. Regression formulae expressing the mean daily range of temperature in each month and the year in terms of the latitude, longitude and altitude above sea level of the station have been worked out. The multiple correlation coefficients, *i.e.*, the correlation between the calculated and the observed values have been found to be significant even at the 1% point except for a few in the case of the North western region. The excess of the calculated values over the observed ones have been charted, and these charts indicate the features that should be given special attention.

Introduction.

In the previous part (Sc. note No. 121), we have discussed the distribution of average surface temperature over India by expressing it as a function of position and time and in this part the mean daily range of temperature has been studied in a similar manner. The aim is to represent all climatic elements by a set of simple equations, which will facilitate easy computation of the different elements and recognition of the inter-relationships between them.

There are two ways of reckoning the mean daily range of temperature, (*i*) the periodic amplitude meaning the difference between the mean temperature of the warmest and coldest hour of the day, and (*ii*) the non-periodic amplitude meaning the difference between the mean maximum and the mean minimum temperatures of the month obtained from the readings of the maximum and minimum thermometers or from hourly observations. It can be easily seen that the non-periodic amplitude is always greater than the periodic amplitude and that the disparity is pronounced in winter. In this investigation, we are treating the non-periodic amplitude as the data for the other are not available for all stations.

It is well known that the diurnal range, being the difference between the maximum and minimum temperatures, all factors which affect the maximum and minimum temperatures affect the range as well, is directly associated with topography, the surface conditions of the soil, the distance from the sea and also the latitude. Further, it is also known that the diurnal range of temperature is less in urban areas than in rural ones, and in deserts and dry plateaus it is greatest. Above all the thermal structure of the lower atmosphere has a guiding influence on its distribution.

While what we are concerned with is the diurnal range of temperature at 4 feet above the ground, it will be worth while to know how the same varies with height practically from the ground level to about 35 feet above the ground. This has been studied in the case of Poona by Ramdas([2]) after a long series of specially devised observations made at the Central Agricultural Meteorological Observatory, Poona. The isopleths of the ranges within this layer of 35 feet above ground drawn in *Figure 7* of this reference brings out clearly the interesting fact that the diurnal range of temperature decreases rapidly with height in the first few inches above the surface and more and more gradually at higher levels and that the actual ranges and their lapse with height are generally high in winter and summer and low during the monsoon.

For the distribution of the range of temperature, Okada([1]) assuming the form

$$R = a + b \operatorname{Cos} \varphi + cn + dw,$$

where R is the range, φ the latitude, n the index of continentality* and w the degree of cloudiness, has calculated the coefficients a, b, c, and d from the data of stations in Japan and Eastern China.

As long as any particular form is not supported by theory it is reasonable to assume that the diurnal range of temperature is a single valued function of position and time, or for any particular time as a function of the positional co-ordinates. Thus we represent the range of temperature T_{rt} as

$$=T_{rt}(\varphi, \lambda, h)$$

$$=(T_{rt})_o + \varphi\left(\frac{\delta T_{rt}}{\delta\varphi}\right)_o + \lambda\left(\frac{\delta T_{rt}}{\delta\lambda}\right)_o + h\left(\frac{\delta T_{rt}}{\delta h}\right)_o$$

$$+\text{terms of higher order.}$$

* In the index of continentality was calculated from the formula $n = L \times 10/\Pi R^2$, where R is the radius of the circle described with the observing station at centre and L is the land area within this circle, using a value of 20 Km for R.

As a first approximation, the distribution of the mean diurnal range of temperature can be considered as a linear function of the latitude, longitude and altitude. On this assumption, the best coefficients of the variables in the equation can be worked out by the usual method of least squares. For the method of analysis, the reader is referred to Sec. 4 of Part I.

The latitude, longitude and height above mean sea level of the stations are given in *Table I* of Part I; the regions referred to have the same meaning as in Sec. 6 of Part I. The mean diurnal range of temperature (mean maximum temperature-mean minimum temperature) of the 167 stations are given region by region in *Tables I—IV*. The matrices used in the calculations of the regression coefficients are the same as mentioned in Sec. 6 of Part I The units used in the calculations are latitude 1 minute, longitude 1 minute, height 1 foot and temperature 0·1°F, the origin of co-ordinates being 8°N latitude, 60°E longitude and mean sea level.

The regression coefficients, their standard errors and the multiple correlation coefficients for the different months and the year have been tabulated in *Tables V to VIII* and have been represented graphically in *Figures 1 to 4*.

2. **Discussion of results.**—*Region I.*—In the western half of the Peninsula —and as a matter of fact in the Peninsula as a whole—the regression on altitude is insignificant* meaning that the altitude of the station has no significant effect on the diurnal range of temperature there. Throughout the year the diurnal range of temperature increases as we go towards north, the gradient being a maximum in April and November. The gradient decreases in value during the South-West Monsoon and becomes insignificant in August. The gradients towards East are positive as can be expected due to the presence of Sea to the West of the area under consideration. The gradient attains a maximum in May and falls off later becoming insignificant in December. The multiple correlation coefficients are fairly high and are significant even at the 1% point. There is however, a perceptible decline in the values of the coefficients during the period July to September. It can be seen that during this period, latitude and altitude have practically no influence on the distribution of the range of temperature. So in addition to the nearness to sea, which is given in the longitude term, there are probably other factors, which control the range, *e.g.*, the cloudiness and rainfall associated with the monsoon.

Region II.—In the Eastern half of the Peninsula also the diurnal range of temperature is unaffected by the height of the station. The range increases towards North during the period October to May with a peak value of 1·5°F for every degree increase in latitude in December. The gradients are wiped out during the monsoon season and in fact the conditions are reversed in August, when the range of temperature increases southwards. The regression coefficients on longitude are negative due to the presence of the Bay of Bengal to the East, with a maximum value in April and are insignificant in July and August. The multiple correlation coefficients are significant even at the 1% point in all the months.

Region III.—The regression coefficients on latitude are generally insignificant except in February and May when the ranges of temperature slightly decrease towards North. The range decreases towards East with maximum gradient in April-May and October. During the monsoon the gradients decrease in value and become insignificant in August. The range decreases with increase of altitude with a maximum value of 1·5°F for every 1000 ft., except in July, August and September when the lapse rates of the range are not significant. The multiple correlation coefficients are significant at 1% point in all the months except August, when it is

*If the regression coefficient is more than double its standard error, it is considered to be significant.

significant at the 5% point. During the monsoon months there is a decrease in the value of the correlation coefficients.

Region IV.—The gradients of the range of temperature along the meridians and parallels are insignificant except during the monsoon months when the range increases towards North and West. The range decreases with increase of height during the period November to April and in the other months the gradients are insignificant except in August when there is a slight but significant increase in the range with increase of altitude. The multiple correlation coefficients are rather low but are significant at the 1% point during the monsoon months and at the 5% point in the other months except May.

3. **Anomalies of ranges of temperature.**—With a view to compare the calculated ranges of temperature with the observed ones, the anomalies* *viz.*, the calculated range of temperature—the observed range of temperature were calculated for the months January, April, July and October. The facts brought out by the *Figures 5 to 8* are :—

i. The calculated ranges of temperature are generally in excess of observed ones on the coastal regions and hill stations ;

ii. the divergences are more pronounced in April and January and much less in July and October.

iii. Orography plays an important part in the distribution of range of temperature.

4. **Conclusion.**—A glance at the regression coefficients indicates that in the Peninsula, the diurnal range of temperature is unaffected by the height of the station. The range generally increases towards north and towards the interior, *i.e.*, away from the sea. During the monsoon season the gradient towards the north is wiped out due to the distribution of cloud and rain but the proximity to sea still continues to wield its influence even though in a lesser degree. In North India there is not much variation in the north-south distribution of the range. In the east-west direction during winter and summer. the range increases as we go from Bengal towards Central India and does not have much variation in North-west India, while during the monsoon season there is a very slight increase in the range towards Central India but further West it goes on increasing rapidly. The range decreases with increase of height except during the monsoon months when the lapse rates of the range are not significant ; in Northwest India during August there is even a slight increase in range with increase of height of the station. The packing of the iso-anomaly curves near coast indicates that the influence of the sea is mainly confined to a narrow strip and further inland this influence decreases considerably. In hilly regions, special orographical features play an important part in the distribution of the range.

References.

(1) Okada T—(1931) On the daily range of air temperature, Geo-Physical Mag. Vol. IV, pp. 103-112.

(2) Ramdas L. A.—(1943) The climate of air layers near ground at Poona, Part I—Ind. Met. Deptt. Technical Note No. 3.

*See footnote under Section 8 of part I.

TABLE I.

Normal daily range of temperature in tenths of degrees Fahrenheit.

Region I.

Name of station.	Jan.	Feb	Mar.	Apl.	May	Jun.	Jul.	Aug.	Sep.	Oct	Nov.	Dec.	Annual.
1. Bhuj ..	259	265	281	286	246	175	127	122	173	254	273	269	227
2. Dwaraka .	183	154	114	86	78	71	62	53	78	112	181	198	115
3. Jamnagar ..	257	268	266	247	210	160	126	113	152	231	269	267	214
4. Rajkot .	325	325	330	324	300	219	152	143	194	273	309	322	268
5. Veraval ..	218	209	194	137	76	49	41	43	70	159	209	218	135
6. Surat ..	292	299	295	263	189	135	98	98	130	222	274	291	216
7. Bhavnagar ..	293	292	293	278	268	194	147	145	179	258	281	294	244
8. Ahmedabad ..	271	283	297	299	282	204	146	132	168	249	274	271	240
9. Indore ..	295	307	317	301	268	197	125	112	153	252	290	301	243
10. Akola ..	316	331	330	309	270	208	148	137	167	258	301	321	258
11. Amroati ..	262	276	285	284	272	204	140	133	161	225	244	256	229
12. Buldhana ..	226	238	238	233	238	192	131	123	140	182	204	219	197
13. Khandwa ..	320	326	325	292	257	195	126	115	152	257	311	325	250
14. Hoshangabad	279	296	309	305	270	200	125	111	145	235	273	279	235
15. Bombay ..	162	157	142	128	115	99	89	90	98	133	169	179	130
16. Ratnagiri ..	205	186	151	125	111	94	79	81	94	138	200	217	140
17. Mormugao ..	149	141	122	115	91	91	78	77	82	101	130	145	110
18. Karwar ..	208	190	153	121	102	89	78	77	87	118	176	210	134
19. Malegaon ..	337	351	345	322	296	209	148	152	185	257	302	329	269
20. Ahmednagar	315	329	323	302	294	201	151	160	183	235	276	307	256
21. Poona ..	319	344	343	322	278	170	118	121	160	226	274	308	249
22. Sholapur ..	283	304	305	288	278	214	174	179	178	219	249	272	245
23. Bijapur ..	259	271	269	263	267	195	160	168	172	203	238	266	228
24. Belgaum ..	257	289	300	289	249	132	89	99	138	180	210	234	205
25. Aurangabad .	287	298	299	285	284	213	160	155	176	235	268	285	245
26. Bidar .	229	241	247	240	233	204	168	158	162	189	200	210	207
27. Gulbarga ..	274	284	289	274	264	216	177	171	171	218	242	270	237
28. Raichur ..	222	237	248	237	241	201	172	171	164	179	191	212	206
29. Chitaldrug ..	224	234	244	245	229	164	138	131	163	170	182	209	195
30. Hassan ..	262	280	288	256	218	144	123	137	162	174	192	235	206
31. Bangalore ..	233	260	263	241	225	180	162	162	167	169	176	204	203
32. Mysore ..	238	252	261	245	221	164	153	165	177	175	180	214	204
33. Mangalore ..	193	164	146	155	127	107	99	96	102	115	142	185	134
34. Calicut ..	167	152	138	125	117	91	80	81	93	109	128	158	119
35. Cochin ..	175	160	140	130	121	105	97	95	104	117	131	159	128
36. Trivandrum ..	117	119	111	98	88	75	74	78	81	81	87	104	92
37. Palamcottah	166	199	215	202	206	175	162	177	189	169	144	141	179
38. Coimbatore ..	221	255	262	228	213	175	166	172	183	174	169	190	202
39. Bellary ..	263	280	281	264	249	190	163	171	178	192	213	246	224
40. Mercara ..	206	221	232	205	159	92	69	76	103	134	154	177	152
41. Ootacamund	226	234	222	202	178	120	101	112	133	141	156	205	169
42. Kodaikanal ..	168	187	187	167	148	117	106	112	116	117	118	147	141

TABLE II.

Normal daily range of temperature in tenths of degrees Fahrenheit.
Region II.

Name of station.	Jan.	Feb.	Mar.	Apl.	May	Jun.	Jul.	Aug	Sep.	Oct	Nov.	Dec.	Annual.
1. Chittagong ..	232	235	195	156	134	100	93	96	106	134	176	212	156
2. Noakhali ..	244	229	187	148	132	96	81	82	91	124	187	231	153
3. Barisal .	226	218	204	170	149	106	89	87	100	128	176	216	155
4. Jessore .	240	247	236	215	178	124	102	98	109	141	194	228	178
5. Calcutta	219	220	216	198	170	125	99	93	101	129	175	210	162
6. Saugor Island	182	160	125	108	108	88	75	76	86	108	150	180	120
7. Midnapur .	248	244	254	247	213	146	113	111	118	160	211	245	192
8. Burdwan .	237	246	253	245	202	141	109	102	110	144	193	226	184
9 Bankura .	233	238	256	261	228	163	118	109	120	164	211	234	195
10. Krishnagar .	257	271	262	242	200	142	112	109	116	159	210	248	194
11 Balasore ..	248	233	230	210	187	139	110	101	111	153	210	246	181
12. Puri ..	168	141	112	92	91	84	79	83	92	121	157	186	117
13 Gopalpur ..	180	159	137	108	100	92	85	87	99	133	164	189	128
14. Cuttack ..	232	234	242	236	213	154	114	108	120	158	186	213	184
15. Sambalpur .	266	267	287	280	271	166	104	98	118	173	220	260	207
16. Purulia ..	250	250	273	275	246	179	137	129	143	190	230	253	213
17. Ranclu ..	223	219	234	242	232	161	111	104	121	168	199	222	187
18. Jubbulpur .	289	291	313	306	268	189	117	106	144	235	288	303	237
19. Seoni ..	274	282	298	294	273	197	120	114	148	225	260	275	230
20. Nagpur ..	279	289	302	291	268	199	128	122	153	223	256	275	232
21. Raipur ..	259	259	273	267	252	185	119	109	131	187	227	254	211
22. Chanda ..	305	315	323	299	273	193	130	123	146	219	266	305	242
23. Nizamabad .	291	294	300	276	253	200	148	135	150	213	253	294	234
24. Hyderabad .	243	255	266	250	231	184	143	133	141	190	213	241	208
25. Hanamkonda	225	236	252	245	227	177	130	126	137	184	206	226	198
26. Pamban ..	84	102	125	118	104	100	102	108	109	104	91	81	102
27 Madura .	183	216	232	221	220	204	200	202	194	169	147	156	195
28. Negapatam ..	111	124	129	132	171	152	174	165	158	126	103	101	140
29. Trichinopoly	198	236	249	233	228	204	194	197	194	168	151	161	200
30. Salem ..	238	269	274	244	232	207	198	193	190	182	182	207	218
31. Cuddalore .	148	158	166	153	181	186	174	170	158	137	123	129	157
32. Vellore ..	200	231	251	230	231	187	172	169	167	165	154	178	185
33. Madras ..	167	181	175	156	173	179	170	165	159	142	117	135	161
34. Cuddapah ..	232	254	267	246	228	196	179	175	174	181	186	212	211
35. Kurnool .	278	285	287	252	237	197	168	163	161	195	228	266	226
36. Nellore ..	182	202	222	225	231	193	173	168	169	155	139	158	185
37. Masulipatam	176	182	186	170	182	176	145	137	133	131	120	166	160
38. Cocanada ..	152	159	183	176	174	150	120	112	115	120	119	143	143
39. Vizagapatam..	129	127	126	114	112	110	104	106	103	116	116	127	116
40. Pachmarhi ..	242	242	243	227	205	153	85	78	113	195	232	250	189

TABLE III.

Normal daily range of temperature in tenths of degrees Fahrenheit.

Region III.

Name of station.	Jan	Feb	Mar	Apl	May	Jun.	Jul	Aug	Sep.	Oct.	Nov	Dec.	Annual.
1 Dibrugarh	214	177	172	142	136	128	113	111	118	143	192	224	156
2 Sibsagar ..	203	193	188	153	139	126	115	110	114	135	181	207	156
3 Tezpur ..	212	203	208	163	146	122	116	113	121	147	191	210	162
4 Dhubri ..	207	217	230	177	132	97	77	76	83	118	161	192	148
5. Silchar ..	254	218	228	189	161	132	128	128	136	163	215	249	186
6 Comilla	249	245	221	186	161	115	106	106	116	148	198	242	174
7. Narayanganj.	221	228	212	180	151	108	93	88	97	126	174	207	157
8 Bogra	234	254	270	237	179	121	104	100	109	144	195	223	181
9. Mymensingh	221	227	227	186	147	104	92	91	99	130	179	216	159
10 Rampur Boalia	239	253	264	240	190	132	105	95	101	142	196	227	182
11 Faridpur	229	238	227	202	167	118	93	83	71	125	179	211	164
12 Berhampur ..	227	247	261	249	202	137	107	99	104	134	178	211	180
13 Malda ..	247	265	286	258	205	139	110	104	109	157	212	238	194
14 Sirajganj ..	237	255	261	226	171	116	93	83	93	134	190	224	174
15 Dinajpur .	261	266	284	242	180	123	106	102	108	155	216	255	191
16 Rangpur ..	246	260	268	224	164	122	111	109	116	156	213	244	186
17. Jalpaiguri ..	224	233	240	211	167	129	114	113	122	162	209	232	181
18. Hazaribagh ..	219	228	244	251	279	168	112	107	122	167	197	218	189
19 Daltonganj	289	284	311	313	276	192	133	122	151	236	289	310	242
20 Purnea	264	273	293	266	206	141	109	104	114	163	229	262	202
21. Bhagalpur .	239	247	266	258	216	148	113	104	117	172	229	250	196
22 Dharbangah	224	237	261	251	199	137	100	97	103	147	210	228	182
23. Motihari .	260	273	302	287	225	157	116	111	127	187	258	274	215
24 Chapra ..	233	254	278	275	237	173	121	107	120	179	231	239	204
25. Patna ..	218	233	256	257	220	150	107	97	107	156	207	223	187
26. Gaya ..	239	245	266	272	247	184	130	116	130	188	234	248	208
27. Naya Dumka	247	246	266	258	217	151	116	110	125	172	222	248	199
28. Gorakpur ..	241	253	280	279	239	176	120	112	231	193	243	245	210
29 Benares ..	264	277	303	307	262	185	125	111	138	226	273	275	229
30 Allahabad ..	264	276	302	308	270	194	130	114	146	236	281	280	233
31 Cawnpur .	366	273	294	296	263	196	135	119	174	251	231	282	235
32. Lucknow .	267	274	303	308	271	198	129	121	174	253	302	291	210
33 Bahraich .	251	259	289	293	249	184	131	117	146	224	267	271	224
34 Jhansi ..	252	257	271	269	245	192	131	120	158	239	270	268	222
35. Agra ..	242	253	273	276	252	196	137	126	165	254	278	264	226
36. Mainpuri ..	260	271	306	313	282	210	146	130	168	275	304	283	245
37. Bareilly ..	241	253	285	293	264	198	134	121	151	244	281	268	228
38. Dehra Dun ..	213	223	247	267	251	191	120	108	147	221	237	232	205
39. Nowgong ..	272	286	311	309	273	195	120	109	150	249	291	286	237
40. Satna ..	267	268	288	289	256	179	109	98	131	221	269	280	221
41. Saugor ..	245	250	262	270	257	203	121	109	150	219	242	244	214
42. Darjeeling ..	122	128	142	141	123	97	88	89	95	116	128	127	116
43. Katmandu ..	298	307	329	320	257	191	166	164	184	252	299	312	256
44. Mukteswar ..	150	153	174	187	186	161	122	116	136	165	170	160	157
45. Raniket ..	140	144	162	175	180	152	110	101	124	148	151	147	144

TABLE IV.

Normal daily range of temperature in tenths of degrees Fahrenheit.
Region IV.

Name of station.	Jan.	Feb.	Mar.	Apl.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov	Dec.	Annual.
1. Meerut ..	249	232	287	304	276	207	139	128	172	279	307	283	241
2 Roorkee ..	249	257	289	307	280	220	141	131	175	274	301	284	242
3. Delhi ..	221	229	244	251	238	197	138	126	159	232	255	240	211
4. Sirsa ..	274	279	302	316	295	234	186	176	223	227	344	311	273
5. Patiala ..	241	237	267	272	261	209	153	140	184	281	296	268	233
6. Ambala ..	254	256	274	298	284	224	163	152	198	307	320	290	252
7. Ludhiana	224	282	259	287	292	235	168	154	191	281	289	259	238
8. Lahore ..	270	271	287	311	312	266	199	184	241	337	348	312	273
9. Sialkot ..	233	240	258	279	280	244	178	162	211	298	312	271	247
10. Rawalpindi ..	246	238	247	272	296	279	211	185	243	322	333	294	264
11. Khushab ..	268	251	245	259	271	248	201	188	227	307	327	301	258
12 Montgomery	268	270	283	294	289	248	200	193	241	324	322	295	269
13. Multan ..	259	263	271	287	283	236	198	184	227	303	308	282	258
14. Srinagar ..	136	149	179	210	240	247	213	212	254	293	288	198	219
15. Dras ..	294	325	287	226	262	303	293	290	291	290	279	268	284
16 Leh ..	221	229	236	254	270	277	268	268	284	284	270	229	258
17 Skardu ..	179	196	175	198	228	244	251	257	244	250	246	186	221
18. Gilgit ..	144	156	171	195	236	259	249	239	237	227	211	160	207
19 Peshawar ..	238	234	234	253	288	293	241	214	252	305	312	276	262
20 Dera Ismail Khan ..	281	270	267	276	289	263	206	194	243	320	335	311	271
21. Quetta ..	227	223	248	281	318	326	288	301	364	368	330	273	296
22. Kalat ..	280	282	291	343	384	407	371	386	428	415	378	321	357
23. Pishin ..	267	275	289	317	363	374	340	351	397	395	374	304	337
24. Jacobabad ..	295	297	308	301	334	294	239	225	271	354	354	320	300
25. Hyderabad (Sd.)	254	266	285	296	288	224	181	166	210	276	295	265	251
26. Manora ..	180	165	142	110	102	82	75	74	92	141	185	190	128
27. Bikaner ..	240	242	257	259	251	220	185	171	196	249	269	256	232
28. Jodhpur ..	264	273	282	277	262	216	172	154	193	286	302	274	246
29. Jaipur ..	263	269	286	295	280	221	161	150	203	294	305	285	250
30. Ajmer ..	273	273	279	261	233	189	136	120	158	269	311	293	233
31. Kotah ..	255	262	268	253	233	195	142	118	156	242	273	262	221
32. Deesa ..	321	321	327	323	296	217	150	135	193	306	344	335	273
33. Neemuch ..	287	290	297	285	264	208	136	123	171	266	297	294	243
34. Simla ..	105	109	118	136	140	124	87	74	92	114	113	105	110
35. Chakrata ..	151	156	175	180	175	141	98	92	121	164	170	162	148
36 Murree ..	116	127	142	154	165	171	144	129	143	151	144	129	143
37. Cherat ..	110	118	136	166	197	203	180	162	187	192	166	121	161
38. Parachinar ..	214	206	207	215	239	241	208	201	224	257	252	221	224
39. Drosh ..	161	164	183	201	230	238	237	233	239	239	209	163	208
40. Mount Abu ..	147	146	156	159	169	149	94	77	104	144	155	153	138

TABLE V.

Regression coefficients of normal daily range of temperature on latitude, longitude and altitude of 42 stations—Region I.

	Regression coefficients of normal daily range of temperature on			Multiple Correlation coefficient.	
	Latitude.	Longitude.	Altitude.	R.	R_1*.
January	·1778±·0262	·1124±·0512	·0061±·0039	·75	·50
February	·1950±·0309	·1652±·0604	·0090±·0046	·72	·50
March	·2166±·0356	·2144±·0696	·0103±·0053	·71	·50
April	·2246±·0361	·2414±·0707	·0094±·0053	·72	·50
May	·2140±·0355	·2833±·0694	·0071±·0052	·72	·50
June	·1516±·0239	·2519±·0468	·0007±·0035	·75	·50
July	·0645±·0213	·1702±·0417	·0006±·0031	·58	.50
August	·0427±·0224	·1554±·0439	·0005±·0033	·53	·50
September	·0721±·0230	·1229±·0450	·0024±·0039	·50	·50
October	·1878±·0235	·1338±·0459	·0020±·0035	·80	·50
November	·2215±·0215	·0955±·0421	·0016±·0032	·87	·50
December	·2023±·0243	·0939±·0475	·0042±·0036	·82	·50
Annual ..	·1643±·0246	·1696±0481	·0044±·0036	·74	·50

*Lower limit of R significant at the 1% point.

TABLE VI.

Regression coefficients of normal daily range of temperature on latitude, longitude and altitude of 40 Stations—Region II.

	Regression coefficients of normal daily range of temperature on			Multiple correlation coefficient.	
	Latitude.	Longitude	Height.	R.	R_1*.
January	+·2070±·0402	—·1393±·0456	—·0061±·0118	·76	·54
February	+·1779±·0477	—·1492±·0541	—·0042±·0140	·66	·54
March	+·2031±·0515	—·2135±·0584	—·0086±·0151	·69	·54
April	+·2139±·0517	—·2297±·0587	—·0091±·0152	·71	·54
May	+·1581±·0450	—·2150±·0510	—·0080±·0132	·71	·54
June	+·0468±·0298	—·1505±·0338	—·0061±·0088	·77	·54
July	—·0610±·0261	—·0555±·0296	—·0038±·0077	·80	·54
August	—·0769±·0242	—·0388±0275	—·0026±·0071	·82	·54
September	—·0288±·0222	—·0659±·0251	—·0006±·0065	·79	·54
October	+·1185±·0215	—·1502±·0244	—·0002±·0063	·86	·54
November	+·2157±·0293	—·1573±·0333	—·0022±·0086	·87	·54
December	+·2499±·0401	—·1645±·0455	—·0074±·0118	·80	·54
Annual ..	+·1206±·0315	—·1452±·0357	—·0051±·0092	·71	·54

* Lower Limit of R significant at the 1% point.

TABLE VII.

Regression coefficients of normal daily range of temperature on latitude, longitude and altitude of 45 stations—Region III.

	Regression coefficients of normal daily range of temperature on			Multiple correlation coefficient.		
	Latitude.	Longitude.	Height.	R.	R_1*.	R_5**.
January	—·0678± 0536	—·0595±·0166	—·0129±·0028	·69	·49	·41
February	—·0993±·0452	—·0661±·0138	—·0125±·0024	·78	·49	·41
March	—·0643±·0535	—·0978±·0163	—·0140± 0027	·77	·49	·41
April	—·0824±·0548	—·1546±·0168	—·0116±·0028	·84	·49	·41
May	—·0956± 0398	—·1596±·0121	—·0069±·0021	·90	·49	·41
June	+·0131±·0308	—·1066±·0094	—·0044±·0016	·88	·49	·41
July	+·0411±·0319	—·0285±·0097	—·0018±·0017	·58	·49	·41
August	+·0446±·0318	—·0144±·0097	—·0008±·0016	·44	·49	·41
September	+·0703±·0421	—·0583±·0129	—·0031±·0022	·65	·49	·41
October	+·0484±·0485	—·1350± 0147	—·0082±·0025	·84	·49	·41
November	+·0314±·0539	—·1197±·0164	—·0131± 0028	·78	·49	·41
December	+·0673±·0513	—·0673±·0156	—·0155±·0026	·73	·49	·41
Annual ..	—·0136±·0372	—·0879±·0113	—·0085±·0019	·79	·49	·41

*Lower limit of R significant at the 1% point.

** Lower limit of R significant at the 5% point.

TABLE VIII.

Regression coefficients of normal daily range of temperature on latitude, longitude and altitude of 40 Stations—Region IV.

	Regression coefficients of normal daily range of temperature on			Multiple correlation coefficient.		
	Latitude	Longitude	Height.	R.	R_1*.	R_2**.
January	—·0584±·0468	—·0260±·0416	—·0063±·0031	·51	·54	·43
February	—·0162±·0457	—·0109±·0406	—·0090±·0030	·53	·54	·43
March	—·0564±·0466	—·0056±·0413	—·0066±·0030	·50	·54	·43
April	—·0089±·0492	—·0104±·0437	—·0077±·0033	·44	·54	·43
May	·0533±·0500	—·0786±·0444	—·0052±·0033	·37	·54	·43
June	·1137±·0479	—·1404±·0425	·0007±·0031	·57	·54	·43
July	·1346±·0431	—·1734±·0283	·0047±·0029	·72	·54	·43
August	·1299±·0462	—·1908±·0409	·0066±·0031	·73	·54	·43
September	·1161±·0521	—·2005±·0462	·0037±·0034	·65	·54	·43
October	·0773±·0578	—·1235±·0513	—·0057±·0038	·43	·54	·43
November	·0362±·0557	—·0737±·0494	—·0096±·0037	·47	·54	·43
December	—·0227±·0500	—·0391±·0444	—·0095±·0033	·54	·54	·43
Annual ..	·0381±·0472	—·0883±·0419	—·0034±·0031	·37	·54	·43

* Lower limit of R significant at the 1% point.

** Lower limit of R significant at the 5% point.

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MONTHLY VARIATION OF THE MULTIPLE CORRELATION COEFFICIENT (R) AND OF THE REGRESSION COEFFICIENTS OF NORMALS OF DAILY RANGE OF TEMPERATURE ON LAT (ϕ) LONG. (λ) AND ALTITUDE (H)

Plate I

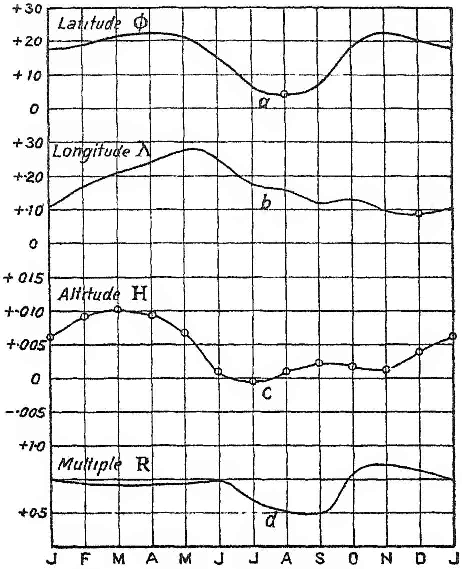

FIG I FOR REGION I

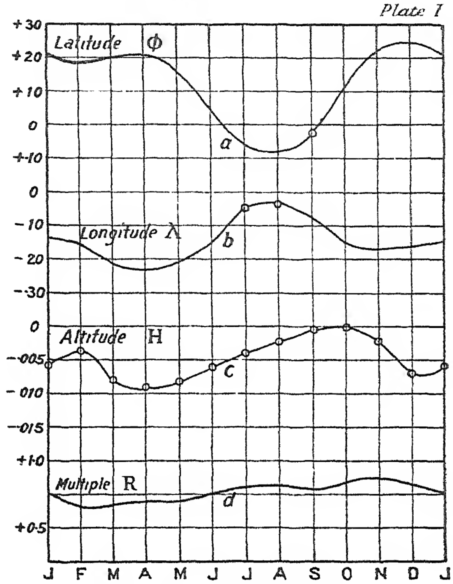

FIG 2 FOR REGION II.

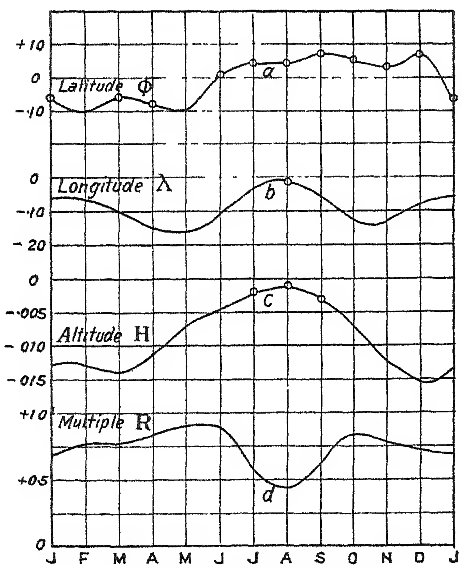

FIG 3 FOR REGION III.

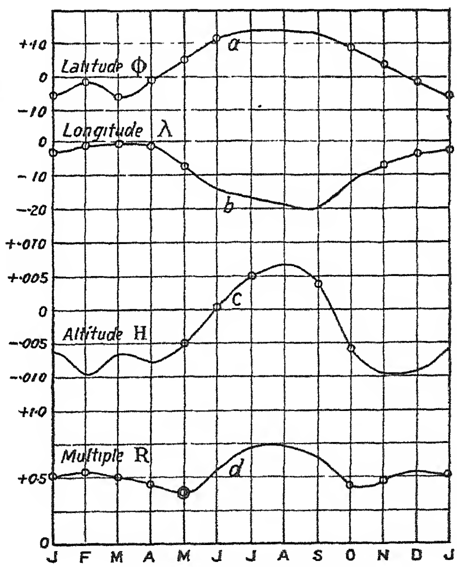

FIG. 4. FOR REGION IV.

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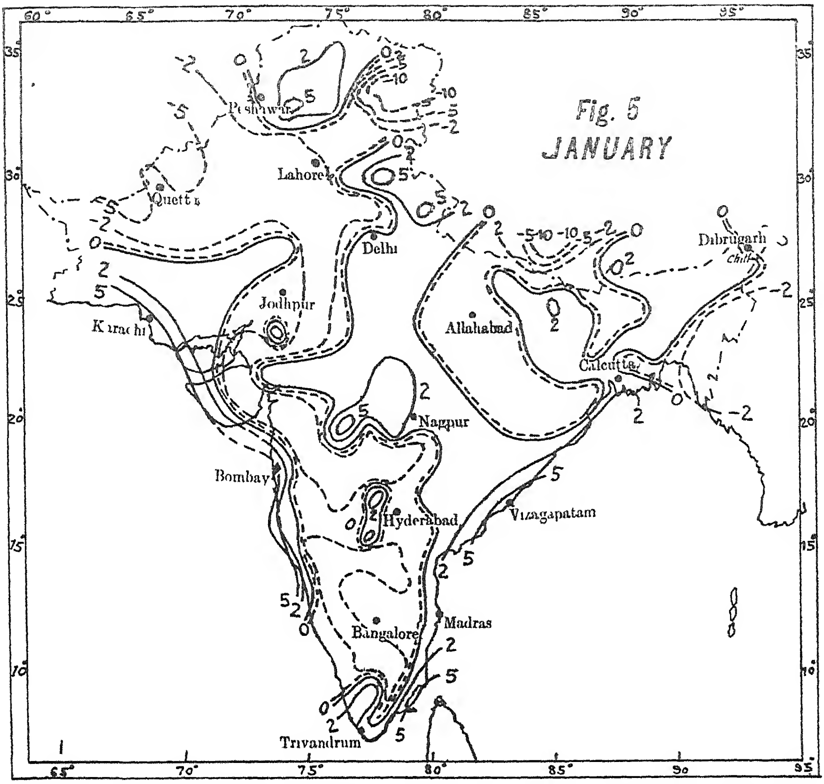
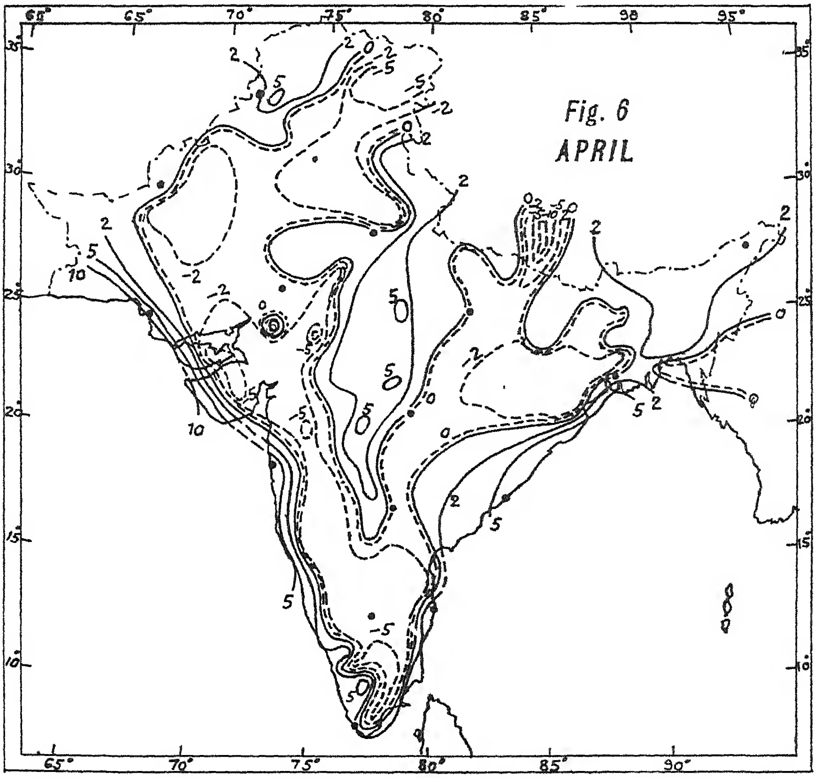
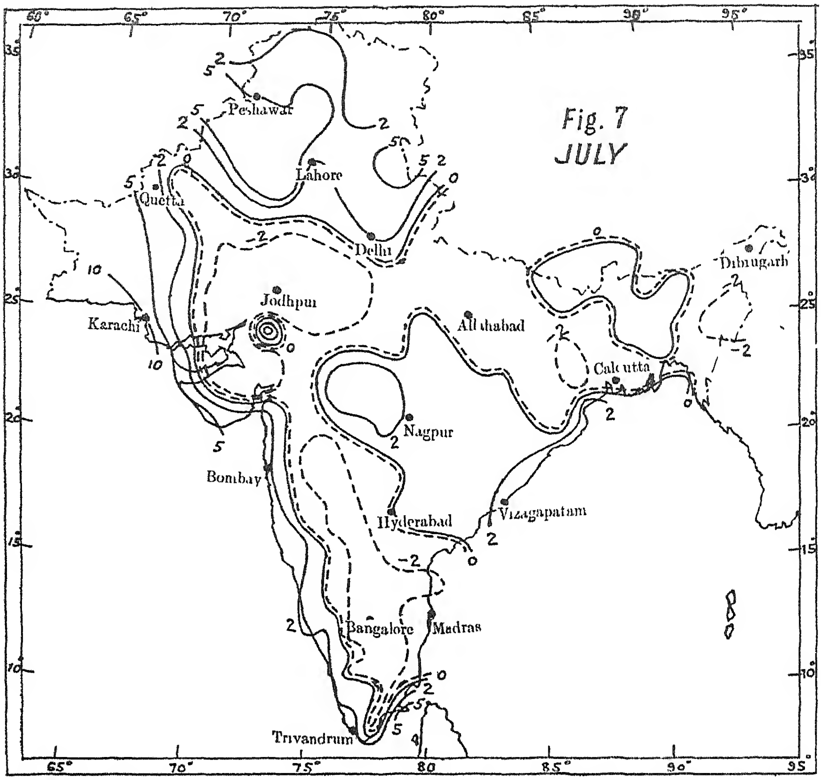
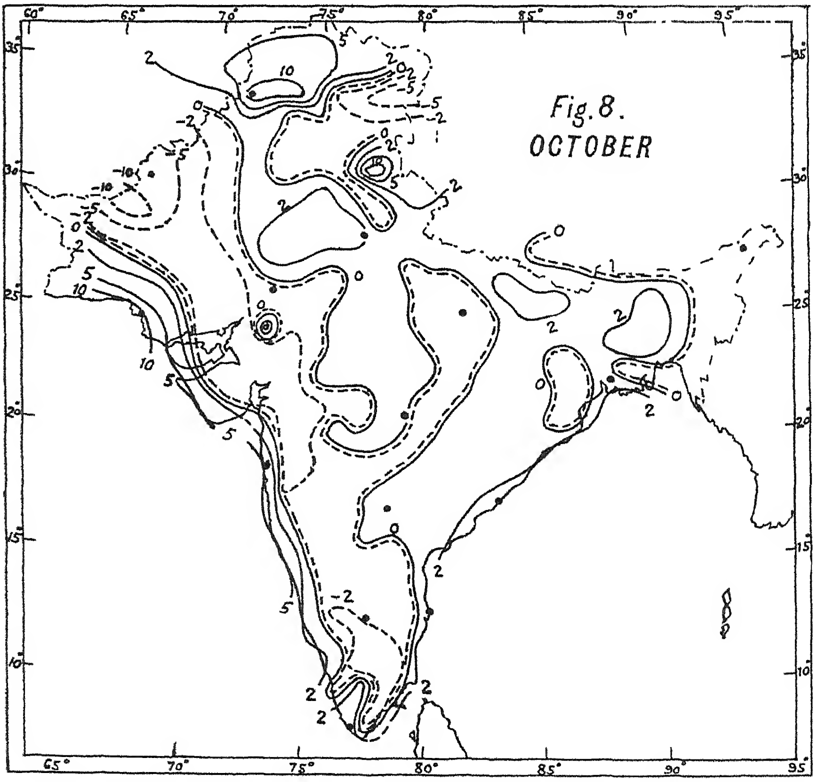




ANOMALIES OF RANGES OF TEMPERATURE





ANOMALIES OF RANGES OF TEMPERATURE

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LOW STRATUS CLOUDS OVER BANGALORE.

BY

P. A. GEORGE.

(*Received on 5th January 1946*).

Abstract—The low stratus clouds over Bangalore are noted for their high frequency of occurrence as well as for their formation at very low heights above ground level The transformations of low stratus into fog and *vice versa* take place quite often over this region. The orography of the country accounts for most of the special characteristics of these low clouds.

The strong vertical inversions within the lower strata of the atmosphere, the distribution of moisture among the various layers, the cooling of the air layers by vertical mixing, and the direction and strength of wind near the surface play a great part in the formation as well as dissolution of the low stratus clouds.

As the general structure and conditions of the atmosphere for the morning could be estimated usually from the radio-sonde data of the previous evening, the tephigrams are found to be of considerable use in forecasting stratus clouds for the next day.

INTRODUCTION.

It is the orography of the country that is often largely responsible for the frequent low stratus clouds over Bangalore. Occupying the southern end of the Deccan plateau, the Mysore plateau slopes gradually to the east eventually merging into the narrow coastal plains ; its southern edge slopes down almost abruptly to the plains of south India. The plateau is dissected over the south by two river valleys forming a ridge in between of average height of 3000 ft. above sea level. Bangalore occupies almost a central position over this ridge. The Cauvery basin lying towards the south-west of Bangalore has an average height of only 1000 ft. a.s.l. The Palar basin lying on its east runs to SE.

Scattered over the plateau, there are many hills of heights ranging from about 4000 to 5000 ft. a.s.l. From the point of view of aviation, low stratus, in a hilly country like Mysore, is as dangerous as any other weather phenomena. Low stratus is a frequent phenomenon at Bangalore, and even during the fine season, the day dawns sometimes with overcast and threatening skies, only to clear off completely after three or four hours and to remain so for the rest of the day. Out of personal experience in forecasting the stratus for aviation purposes, I have observed certain rules and some indications on the synoptic charts and in the soundings of the atmosphere over Bangalore, which are of considerable aid in foreseeing the possibilities of the formation of low stratus clouds there. There were days also when low stratus formed but could not be foreseen with the aid of those rules ; but it has been observed that most of them were on days when there occurred sudden changes in the synoptic situation or in the upper air conditions as well as when stratus was blown over from distant places.

Modes of cooling.—Of the different modes of cooling of the atmosphere (*i*) cooling by radiation, (*ii*) adiabatic cooling due to vertical lifting and consequent expansion and (*iii*) cooling by vertical mixing, are the most important ones which aid the formation of stratus clouds. Cooling by contact with colder surface or with colder air masses also occur. Of these, cooling by vertical mixing plays a greater part in the formation of low stratus.

Distribution.—During the monsoon season quite extensive stratus layers form over the plateau covering the entire sky for the major part of the day ; while, in the non-monsoon season, stratus forms more often as a local phenomenon and get drifted to the neighbouring places as broken stratus (Fs.) There are many days in a year when Yelahanka, Kolar or Mysore reported stratus while Bangalore was clear. Widely extended sheets, sometimes covering vast areas, are also found in winter months, very closely associated with the stratified conditions of the lower atmosphere. On days when the coastal areas due east or west of the Mysore plateau were raining, and when the upper winds at lower levels over the plateau had trajectories over these rain areas, the plateau got widespread sheets of stratus which sometimes persisted for the whole day.

Height.—It has been observed that usually the height of the base of the stratus over Bangalore is a little above 1000 ft. *a.g.l.* There is quite a considerable number of occasions in a year when the base falls within 600—1000 ft. above ground. The number of days when the base is between 300 and 600 ft. above ground is small. There are a few occasions when the base lowers to below 300 feet above ground and touches the ground to persist for a short time as fog.

Generally, the clouds are found to attain their lowest height after sunrise which is accounted for by the facts :—(1) The air layers a few hundred feet above the ground reach the minimum of the day only after sunrise as a result of the time lag in the diurnal cooling (2) The vertical mixing of the lower layers of the atmosphere takes place soon after sunrise.

The lowering of the base of the stratus clouds occurs when it is raining or drizzling through the clouds, especially when there is an inversion just within or immediately below the stratus layer. The level upto which the base can lower is limited by the level A in *Fig. 1.*

Time and frequency of occurrence.—The usual time of occurrence of stratus has been found to be early morning by about sunrise. On occasions when the stratus clouds form as early as 0300 hrs. they decrease in amount and sometimes disappear by 0600 hrs. but often reform again just after sunrise. The time of final dissolution depends on the synoptic situation as well as the upper air conditions of the atmosphere.

During the monsoon season when the winds are generally strong and the moisture content of the atmosphere is very large up to a considerable height the stratus starts very much earlier, sometimes before midnight, and continues till next noon with the characteristic diurnal decrease in amount just before dawn and increase after sunrise.

The frequency tables given at the end show that February, March and April are the three months having the least number of days of stratus, and of these April has the minimum. June, July and August are the months with the greatest number of days of stratus, July and August having the maximum. The above frequency table is based entirely on 0900 hrs. observations. As sufficient observations at all the synoptic hours are not available for calculating the normals the cloud amounts as observed throughout the year 1944, are represented diagrammatically (in *Fig. 2*).

The relation of stratus with the direction and strength of wind.—The direction and strength of wind from the surface upto about 5000 ft. a.s.l. have direct influence over the formation of stratus clouds. The most favourable directions of the surface winds as well as the upper winds upto 5000 ft. a.s.l. are E to S E and SW to W (See *Table I*). So far as the lifting of the air layers is concerned, the directions of wind between E and SE and between W and SW are very effective and in addition, air masses from these directions are likely to have had some sea travel and greater moisture content in the lower layers.

Since strong winds from these directions contribute to a thorough vertical mixing of the lower strata of the atmosphere and a rapid vertical lifting of the air layer along the slopes of the edge of the plateau, one may expect a greater chance for the development of the stratus with strong winds at the lower strata of the atmosphere. Observations tabulated in *Table II* support the above expectation. The increase of frequency on the calm days is apparently a result of greater nocturnal cooling or stronger inversion, as well as of the formation of stratus by the lifting of fog.

Association with fog.—According to Taylor " a fog on high land may be due to the forcing up of air from lower-lying land by the contours of the ground, but a fog of this nature is practically the same thing as the lower surface of a cloud into which the high land is projecting ". This is quite true of the fog and stratus at Bangalore. It is a frequent phenomenon, especially in the winter months, that the fog that forms during the night or early morning lifts gradually after sunrise and moves over as low stratus to a neighbouring place.

If the sky is clear the ground cools during night and the ground subsequently cools the air layers close to the ground. Consequently a ground inversion is established which persists throughout the night until disturbed by strong turbulent mixing of the air layers (*Fig. 3.*). It is the persistence of this ground inversion during the night which is favourable for the formation of the fog in the early morning, provided other favourable conditions also exist. But just after sunrise, the increased turbulence produces vertical mixing and destroys this ground inversion and thereby dissipates the fog.

On certain days, especially during the winter months, there is already a pre-existing inversion below a height of about 1 km. above ground (*Figs. 4 and 5*). During night the ground inversion combines with the inversion existing just above it to form a strong and deep inversion layer extending from the ground up to 1 km. above ground. On such days the fog that is formed, instead of getting dissipated, is lifted up to the base of the pre-existing inversion and drifts overhead as low stratus with the destruction of the ground inversion soon after sunrise.

The stratus in relation to the anticyclone of the winter months.—It is quite a common feature, that after a long spell of the flow of the northerly and northeasterly dry cold air over the plateau during winter, the surface winds as well as the upper winds up to about 5000 ft. a.s.l. take a sudden turn and begin to blow from a direction between E and SE over the North Coromandel coast as well as the Mysore plateau. This is found to be usually due to the shifting of the seasonal anticyclone in Central India over to the east C.P. or Circars coast or due to the splitting up of the wide anticyclone into small anticyclonic cells of which one may move over to this region.

Such a situation provides favourable conditions for the formation of fairly widespread stratus over the Mysore plateau on account of the following facts : (1) SE'ly direction of wind gives good vertical lifting for the lower air layers during its ascent over the edge of the plateau (2) there is an increase in the humidity mixing ratio of the lower layers as a result of the trajectory of the air over the sea (3) the contact of this warm and moist SE current with the existing colder air over the plateau brings about further cooling and condensation.

By the end of February and early March there exists an anticyclone below 1 km. level over the Bay of Bengal. Its diurnal oscillation between the land and the sea has been observed on certain days to be so marked as to affect the winds upto even 5000 ft. a.s.l. The extension of this anticyclone into the interior of the land takes place late at night so that the winds upto about 5000 ft. a.s.l. over the Mysore plateau begin to flow early morning from S to SW'ly directions. This sudden turn of the wind is found to bring almost invariably low stratus in the morning for Mysore plateau (*Figs.* 6 and 7 and attached explanatory notes on page 10).

Association with rain.—Although, overcast stratus clouds give a gloomy and threatening appearance to the skies, generally it is not associated with any rain But thick stratus clouds, particulary in the monsoon season are known to give some passing drizzle, sometimes of heavy and intermittent nature. For example, on the 25th November 1944, the stratus that started early morning continued for the whole day and night giving heavy, intermittent drizzle. The continuous supply of moisture was maintained as the upper winds were easterly having their trajectory over the east coast which was experiencing continuous rain during that day. The aerological ascent as well as reports from aircraft confirmed that there existed only stratus clouds with the base below 1000 ft. above ground and having thickness of 2000-3000

Use of Tephigrams in the forecasting of Stratus clouds.—Soundings of the upper air, particularly in the evening, are found to be of considerable use in forecasting stratus clouds for the next day. The success of forecasting stratus based on the thermodynamic diagram depends on the persistence of the upper air conditions, with its normal diurnal changes in the lower strata of the atmos-

phere, till the next day and also on the correctness with which the diurnal change could be estimated.

The outgoing radiation cools the ground at night. The consequent lowering of temperature is transmitted to the air layers near the ground by Conduction, Radiation and Turbulence. The effect of conduction is so small on the air layers a few feet above the ground that we can neglect it for all practical purposes. Radiation also is of slight importance in the spread of heat upward to any considerable height above the ground when compared with the effect of turbulence so that there is not much error in considering turbulence as the main agent in effecting the transfer of heat through the lower layers of the atmosphere.

Taylor's equation of the diffusion of heat by eddies or turbulence as modified by Brunt is, $\frac{\delta T}{\delta t} = K \frac{\delta^2 T}{\delta z^2}$ where T is temp., t time, z height and K eddy diffusivity.

Assuming that the vertical transfer of heat is entirely by turbulence, and that K is constant with height the diurnal variation of temperature at any height z from the ground on clear days is given by the equation.

$T = T_o + \beta z + Ae^{-bz} \sin (qt - bz)$. *

Where b is a constant defined by $b^2 = q/2K$; the term βz is included to allow for the mean lapse rate during the period. So the amplitude of the diurnal variation of temperature at a height z bears to the diurnal variation at the ground the ratio e^{-bz}. K varies with the height, season and strength of wind. Taking a mean value of 10^5 for K the ratios of the diurnal variation of temperature at different heights to that at the ground are calculated.

Ht. in Km.	0·0	0·3	0·45	0·6	1·0
Amplitude in degrees ..	1·0	0·55	0·40	0·30	0·14

Thus theoretically, the diurnal variation of temperature at a height of 1 km. above ground is 14 per cent of that at the ground. Actual observations at Bangalore have shown that the air layers at 1 km. above ground are not generally affected to any tangible amount by the diurnal variations of temperature even when the sky is clear. Hence for practical purposes we may consider 1 km. height to be more or less the limit upto which the diurnal variation of temperature extends. It will be seen from *Figs. 8 and 9* that the temperature at 1 km. a.g. are practically the same.

The time lag in the occurrence of the maximum and minimum at a height z from the ground is given by the relation (b/q) z which comes to a little over two hours for $z = 300$ metres. Hence the minimum temperature of the day should occur at a height of 300 metres above ground only two hours after sunrise.

The above considerations help one to estimate the approximate conditions of the atmosphere for the next morning, so far as the temperature is concerned. But the change in the distribution of water vapour cannot be estimated with any degree of accuracy. Even though the diurnal variation of humidity mixing ratio of the atmosphere is considered to be negligibly small, an increase or decrease of 1—2 gms. within 12 hrs. for the value of the humidity mixing ratio for the lower layers of the atmosphere is not uncommon over Bangalore, particularly in winter months.

*Physical & Dynamical Meteorology by David Brunt Chapter XII.

Hence, in estimating the chances of condensation of water vapour as well as the level of the condensation for the next day, based on consideration of the humidity content of the atmosphere obtained from a radio-sonde ascent, one should give allowance for the above-mentioned variation in humidity content even though the actual factors influencing the variation are not yet fully understood.

Vertical mixing in non-saturated air (1) No condensation taking place.—The effect of thorough vertical mixing in a non-saturated air so long as condensation does not take place is to render the lapse rate of the dry bulb temperature equal to the dry adiabat and render the wet bulb temperature follow the saturation adiabat.

(2) **Condensation taking place in a portion of the air column.**—Once the air becomes saturated at any portion of the air column, condensation takes place as the air layers cool further as a result of vertical mixing. The dry bulb and the wet bulb temperatures for the saturated portions coincide and thorough mixing of the air layers will make the dry bulb curve coincide with the saturation adiabat. Normally the absolute humidity decreases with increase of height, particularly so, during late night and early morning when turbulent mixing is at a minimum. In such a situation mixing transports water vapour upwards. On the other hand, with a lapse rate smaller than the dry adiabatic, the potential temperature increases with height and mixing tends to transport heat downwards and thereby cool the upper layers of the mixed portion. Thus in a stably stratified part of the atmosphere turbulent mixing tends to bring about condensation in the upper layers as a result of the upward transport of moisture and the downward transport of heat.

The results may be summarised as follows :—(1) The effect of vertical mixing is to establish a dry adiabatic lapse rate below the condensation level and moist adiabatic lapse rate above it. (2) In a limited layer of air which is originally non-saturated, vertical mixing can cause condensation only in the upper portion.

The lowest level at which condensation occurs as a result of vertical mixing is called the " mixing condensation level ".

The following rules for finding the height of the mixing condensation level are found to be useful in practice.

(1) Find the *mean potential temperature* of the air column before mixing and mark the dry adiabatic that corresponds thereto.

(2) Find the *mean potential wet-bulb temperature* of the air column before mixing and mark the moist adiabatic that corresponds thereto.

(3) Then the point of intersection of these adiabatic lines indicates the mixing condensation level.

The determination of the mixing condensation level in the above manner involves firstly the determination of the thickness of the mixed layer and secondly the assumption that the layer is completely stirred.

The thickness of the stirred air column depends upon the strength of the wind, the stability condition of the air column and the orography of the country.

As complete mixing occurs rarely the actual cloud base is usually higher than the mixing condensation level as determined above.

*Fig. 10** shows a typical example of the result of vertical mixing in a limited air that is originally non-saturated. The lapse rate of the air column before mixing is represented by T and the relative humidity of the different layers by the line R in *Fig. 10(a)*. After complete stirring, the relative humidity of the different layers depends upon the thickness of the mixed layer and is represented by the various curves shown in *Fig. 10(b)*. It is seen that the mixing condensation level also depends upon the thickness of the mixed layer and that condensation does not occur if the mixing does not extend above a certain height of the air column.

The diagram shows that the deeper the mixed layer the higher will be the mixing condensation level (*i.e.* the base of the stratus) and the greater the thickness of the saturated air column (thickness of st. formed).

It has been observed that inversion plays a great part in the formation as well as the dissipation of stratus clouds.

Let ABCD (*Fig. 11*) represent the estimated Tephigram extending from the ground up to about 1 k.m. height above the ground at the instant when the air temperature near the surface has reached the minimum on a day when there is an inversion existing beneath the 1 km. level. If complete churning of the air layers from A to C takes place within a few hours after sunrise, the resultant Tephigram will be represented by A′B′C′D′, where A′B′ lies along the dry adiabat and B′C′ along the wet adiabat indicating that the air layers within B′ and C′ are saturated so that B′ will be the base and C′ the top of the clouds formed.

If the mixed layer is completely churned, the humidity mixing ratio of the air column in which no condensation has occurred will remain uniform throughout so that the S—T gram of the column will lie along the moist adiabatic corresponding to the mean wet bulb temperature of the air column. Hence the mixing condensation level is at B′. As complete mixing occurs rarely the transportation of moisture from one layer to the other does not take place to such an extent as to equalise the humidity content. Consequently the actual cloud base is usually higher than the mixing codensation level.

With the diurnal heating of the ground and the air layers close by, convection sets in and the vertical mixing extends further up and raises the condensation level. By the time the condensation level reaches the base of the inversion the stratus clouds get broken up into Fractostratus and dissolve gradually.

The dissolution depends also on the difference of humidity content between the air above and below the base of the inversion. When the air above is very much drier than that below, the tendency is for the stratus to dissolve completely as soon as the condensation level reaches the base of the inversion (e.g. *Fig. 9*). On the other hand, if the relative humidity is nearly equal or higher above (as is usually the case during rainy days), the stratus persists with its base probably lifted up with the diurnal lifting up of the condensation level (e.g. *Fig. 12*). But if it rains through the inversion

*Taken from Petterssen's "Weather Analysis and Forecasting"

layer, the base of the cloud builds down to the level where the isotherm through the top of the inversion cuts the Tephigram below it.*

A strong layer of inversion near the ground is found to be favourable for the formation of low stratus so low as the *lifting condensation level*, provided there is sufficient steady movement of the air layers up the slope of the plateau so as to lift the *air layers as they are* without much mixing.

Although a pre-existing inversion at some distance above the ground is very much favourable for the formation of low stratus, it has also got the counteracting influences. It suppresses the turbulence, and retards the diurnal cooling of the air layers underneath due to the radiative exchange of heat between the warmer layers aloft and the colder air below.

On days when there is no pre-existing inversion at some height above the ground, if the sky is clear the range of the diurnal variation of temperature becomes large. On such days the turbulence extends higher and with the existence of other favourable conditions, stratus form earlier and dissolve quickly.

Analysis of Typical Aerological Ascents at Bangalore.—(a) Ascent at 2330 hrs. I.S.T. on 30th March, 1944 (*Fig. 3*).

It is presented just for the purpose of showing how the ground inversion is established during night which is very strong but shallow before midnight. By morning it becomes weaker but its depth increases, sometimes extending up to 800 mb. level or even higher, as a result of the cooling extending to the upper layers.

(*b*) Ascent on 9th December 1944 at 1830 hrs. I.S.T. (*Fig. 4*).

Ascent on 10th December 1944 at 0930 hrs. I.S.T. (*Fig. 5*).

For both the ascents the humidity mixing ratio values for most of the levels were not available.

Fig. 4 shows that there was already an inversion existing on 9th evening between the 813 and 795 mb. levels. With the minimum temperature reaching 57°F on 10th morning, as could be seen from the previous days' minimum temperature, an inversion extending from the ground up to about 800 mb. level (a height of more than 3000 ft. above ground) could be expected for the next morning. Moreover, the lifting condensation level for the surface layers would come down from 800 mb. on 9th evening to nearly 900 mb. on 10th morning so that very low stratus or fog for 10th morning could evidently be foreseen.

---

*Let there be an inversion existing between the two levels B & C as shown in Temp-height curve (*Fig. 1*). Suppose that the base of the rain cloud is at the level B. The rain drops falling through the air layers between B and C will be warmer than the air layers just below B so that the falling rain supersaturates the layer AB causing condensation. Consequently the cloud layer builds downward until it reaches the level A below which no supersaturation is possible as the air is warmer than the falling rain-drops.

The ascent on 10th December 1944 at 0930 hrs. I.S.T. shows that the temperature of the air layers near 800 mb. level increased by 1-2°F and that near 820 mb. by 4°F so as to intensify the inversion which could suppress any amount of vertical turbulence. The ascent shows that by about 0930 hrs. the vertical turbulence extended only up to about 890 mb. level (nearly 600 feet above ground). The slightly super-adiabatic lapse rate which appears to extend from the ground up to 890 mb. level actually exists only near the ground. Above that, the mixed layer would be partly dry adiabatic and partly moist adiabatic, which could have been seen if only we have observations at closer levels in the mixed layers.

On the 10th morning low stratus started by 0600 hrs. covering about half the sky. The amount suddenly increased and the base lowered to form widespread and thick fog over the Mysore Plateau. By 0930 hrs. the fog lifted up and moved overhead as low stratus which lasted till noon. The minimum on 10th was 57°F and TsTs at 0900 hrs. also was 57°F.

(*c*) Ascent on 15th February 1945 at 1830 hrs. I.S.T. (*Fig. 6*).

Ascent on 1st March 1945 at 1830 hrs. I.S.T. (*Fig 7*).

Both the Figs. 6 and 7 are typical examples leading to the failures when the forecast is based entirely on the Tephigram, neglecting the synoptic situation. With the minimum coming down to 67°F on 16th February 1945 and to 67°F on 2nd March 1945 a good inversion would be established on the mornings of 16th February and 2nd March from the ground up to about 800 mb level. But the moisture content was so low that any lifting or mixing of the layers would not be able to effect condensation below 800 mb. level.

On the night of 15th February 1945 the surface winds as well as the upper winds up to 5000 ft. a.s.l. turned from E to SE and the speed increased. The surface wind became strong and gusty from 2000 hrs. The TsTs value at 2300 hrs. showed a considerable increase over its value at 1800 hrs. The next day's RAOB also showed that there was an increase during night of 3·4 gms. at the lowest layer and 2 to 3 gms. for the upper layers up to about 5000 ft. a.s.l. for the values of the humidity mixing ratio. With the mixing ratio value for the lowest layers increasing to nearly 10 gms. by 16th morning the SE wind could lift the stable layers underneath the inversion to the condensation level which would be near 830 mb. level.

On the 16th morning the sky remained clear till 0300 hrs. At 0600 hrs. the sky was covered with 9/10 stratus clouds of base above 2000 ft. above ground. By sunrise the base lowered a little and the sky remained 7—10/10 covered till 0900 hrs. Then the clouds dissolved gradually and disappeared completely after 1000 hrs.

Fig. 7 shows that the situation was more or less the same on the evening of 1st March 1945 as on 15th February. With such a situation one could preclude entirely stratus clouds for the next morning. But during the night the seasonal high that was

existing in the Bay extended over to the Mysore plateau changing the surface wind as well as the upper winds over Bangalore from their initial direction of E during the evening to SW/W by next morning. Unfortunately there was no ascent on 2nd March which would have indicated the actual increase in the humidity content.

On 2nd March just after 0600 hrs. some 2—3/10 Fs clouds were seen moving over head from SW which cleared soon. Just after sunrise the sky became covered 7—10/10 all of a sudden the base of the clouds being 300-500 ft. above ground. By 0900 the sky was covered 7/10 and the base was lifted to 600-1000 ft. above ground. Just after 0900 hrs. the sky cleared.

(*d*) Ascent on 20th November 1944 at 1830 hrs. I.S.T. (*Fig. 8*).

Ascent on 21st November 1944 at 1830 hrs. I.S.T. (*Fig. 9*).

A comparison of the two ascents will show the effect of the diurnal cooling and vertical mixing on the shape of the Tephigram. Both at 1830 hrs. I.S.T. on 20th and at 0930 hrs. the next day the temperature at 800 mb. level remained constant at 59°F, while the air layers below 800 mb. level have been affected by the diurnal cooling. The minimum on 21st was 65°F. so that an inversion, (excepting the shallow ground inversion), was not likely to occur. By 0930 even the shallow ground inversion was destroyed by vertical mixing which extended up to 870 mb. The lifting condensation level at 0930 was at 880 mb. so that the thickness of the stratus could not be more than 300 ft. Since there was only an isothermal layer above, the vertical mixing would extend upward quicker thereby raising the condensation level to the region where the air layers were drier than that below so that the stratus could break up soon.

On 21st November 1944 the sky was clear till 0300 hrs. I.S.T. The 0600 hrs. observation showed 5/10 stratus which increased to 7/10 by 0900 when the base was given by code fig. 4. It disappeared during the next hour. The surface wind in the morning was NE about 10 p.m.h. while the upper wind from the ground up to 2000 ft. above was ENE/NE, 20-25 m.p.h. which was strong enough to effect sufficient vertical mixing.

(*e*) Ascent on 22nd July 1944 at 2230 hrs. I.S.T. (*Fig. 12*).

The ascent shows the general conditions of the atmosphere during the monsoon months when the humidity content is very high from the ground to a considerable height. During monsoon the wind is generally strong and inversions are rarely found within the lower layers of the atmosphere. In the figure, a lapse rate, approaching the value of dry adiabatic is found from the ground up to 820 mb. level, so that any little turbulence could bring about the required vertical mixing up to a good height. Hence usually during the monsoon season, through the *lifting condensation levels* of the evening ascents indicate lower stratus for the next morning, because of the thorough vertical mixing, condensation starts only at the mixing condensation level which is usually higher than the lifting condensation level.

The minimum on 23rd was 66°F. so that either fog or stratus below 300 ft. above ground could be expected if condensation was to occur at the lifting condensation level of the lower layers. However, this was not possible as the strength of the surface wind, which was westerly, was more than 10 m.p.h. Hence the strong turbulence that ensued resulted in good mixing and raised the condensation level.

On 23rd morning the sky was almost clear at 0300 hrs. while it was overcast with stratus by 0600 hrs. At 0900 hrs. also it remained overcast with base 3 (code fig.). The west coast was raining throughout the day so that there was a continuous supply of moisture from the west. Hence the stratus clouds, though slightly broken persisted till evening with base lifted to nearly 2000 ft. above ground at noon. The base lowered a little in the evening.

Conclusion.—Thus the evening or night aerological ascents of the station gives to the forecaster direct information regarding the structure of the different layers of the atmosphere over the station. This information, together with a thorough knowledge of the synoptic situation, helps him to decide the possibilities of the formation of stratus clouds over the station for the next day.

I take this opportunity to express my grateful thanks to Mr. S. Basu and Mr. P. R. Pisharoty for the valuable suggestions and guidence given to me in preparing this note.

NOTE :—The time refers throughout this note to the Indian Standard time in existence during the war period ($6\frac{1}{2}$ hrs. ahead of G.M.T.).

Table I.

Directions of Wind	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	N	Days not reported
Total number of days in the year 1944* when the wind near surface at Bangalore as shown by the dawn p.b. ascent, had the respective directions.	2	22	15	47	23	33	11	12	6	42	44	69	12	6	4	4	13
No. of days when stratus existed between 0600 and 0900 hrs. with the corresponding wind directions.	2	14	6	38	13	21	6	2	3	30	34	61	8	5	1	..	7
No. of days when base was code fig. 3 or less during the period 0600-0900 hrs. with the corresponding wind directions.	..	3	2	16	5	6	2	..	1	10	9	18	..	..	..	..	1

* The year 1944 was chosen as that being the only year when observations were available both for 0600 and 0900 hrs.

Table II.

1. Wind force in code figure	6	5	4	3	2	1	Calm	Not reported
2. Total number of days in the year 1944 when the wind near surface as reported by dawn p.b. ascent had the respective velocities.	14	38	93	149	49	10	7	6
3. Number of days when stratus existed between 0600 and 0900 hrs. with the respective wind velocities.	13	30	66	105	25	3	5	..
$\frac{\text{Row 3}}{\text{Row 2}} \times 100$	93	79	71	70	51	30	71	..

TABLE III(a.)

The figures in the columns give the number of days in the respective months, and years when stratus clouds were reported to have the corresponding heights of base above the ground (based on observations recorded at 0900 and 1800 hrs. only).

Year.	Heights of base of stratus cloud (code fig.)	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	August.	Sep.	Oct.	Nov.	Dec.
1944	4	..	8	14	4	2	21	20	22	13	15	12	9
	3	17	4	1	..	7	7	6	5	8	3	2	4
	2	..	1	..	..	..	..	1	..	..	..	..	..
	1	..	..	..	..	..	1	.	.	..		..	..
1943	4	6	4	4	6	16	26	20	30	21	15	16	10
	3	3	..	1	..	4	1	11	..	7	5	7	2
	2	1	..	..	..	..	..	..	..	..	1	1	2
	1	..	..	..	..	..	..	..	..	..	.	..	.
1942	4	..	..	1	2	3	9	20	16	2	...	7	12
	3	..	1	..	..	..	..	..	..	..	..	..	4
	2	..	..	..	..	..	..	..	..	..	..	..	1
	1	..	..	..	..	..	..	..	.	..	..	..	..
1941	4	..	..	3	..	1	4	6	13	7	7	4	3
	3	..	..	..	..	..	4	2	..	3	8	..	1
	2	..	..	..	..	..	2	..	..	..	3	..	..
	1	..	..	..	..	..	.	..	..	..		.	..
1940	4	10	1	..	..	2	3	1	7	..	2	4	2
	3	..	..	..	..	1	1	..	..	1	..	3	..
	2	..	..	..	..	..	..	..	..	..	..	..	..
	1	.	..	..	..	..	..	..	..		.	..	..
1939	4	9	3	7	7	12	24	27	17	10	12	6	16
	3	2	..	1	2	..	..	..	8	3	2	2	..
	2	..	..	..	..	..	..	..	..	..	..	1	..
	1	..	..	..	..	..	..	..	..	..	..	..	..
1938	4	13	10	8	11	13	26	29	24	23	19	7	15
	3	2	1	1	..	2	2	1	5	3	1	..	2
	2	..	..	..	..	..	..	..	..	1	..	..	..
	1	..	..	..	..	..	..	..	..	..	..	..	..

TABLE III(*b*).

Average (of 7 years) number of days of stratus during each month.

Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.
9	5	6	5	9	19	21	21	12	13	10	13

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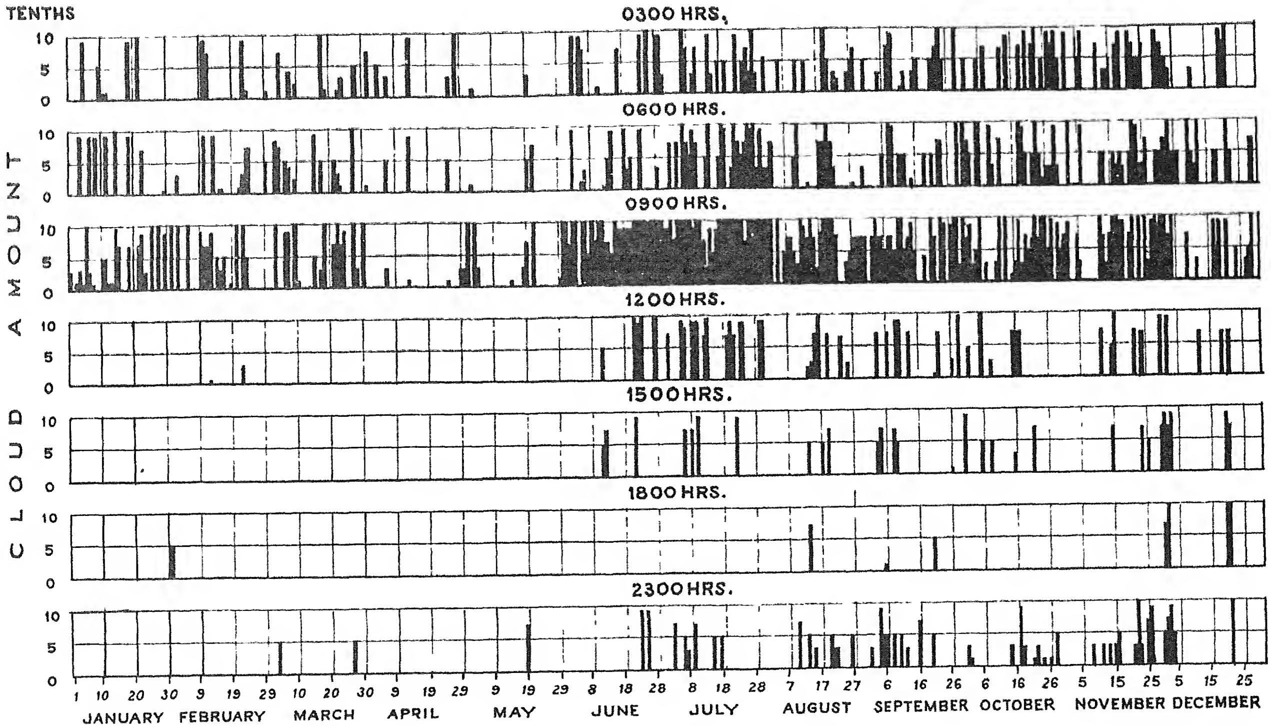

FIG 2.

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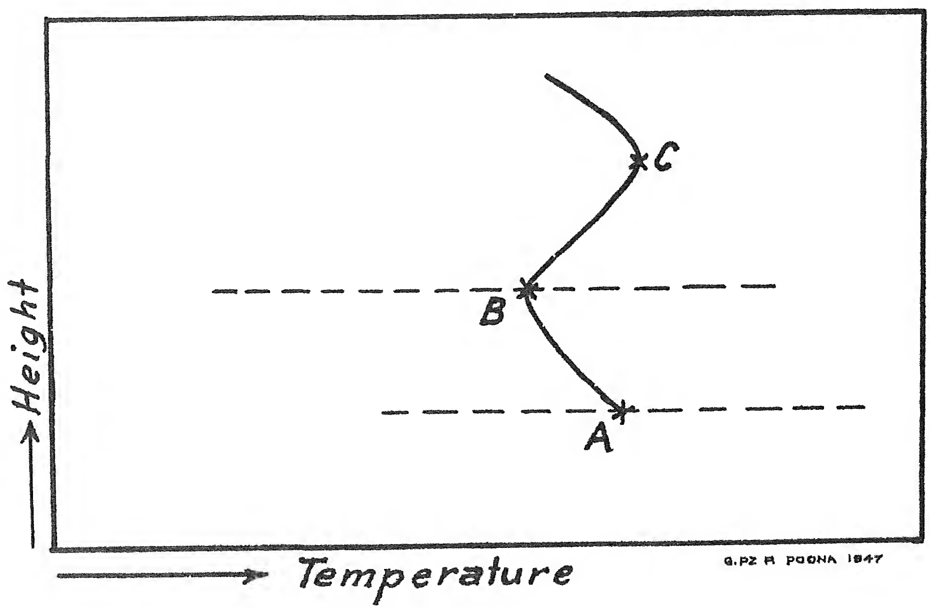

FIG. 1.

BANGALORE

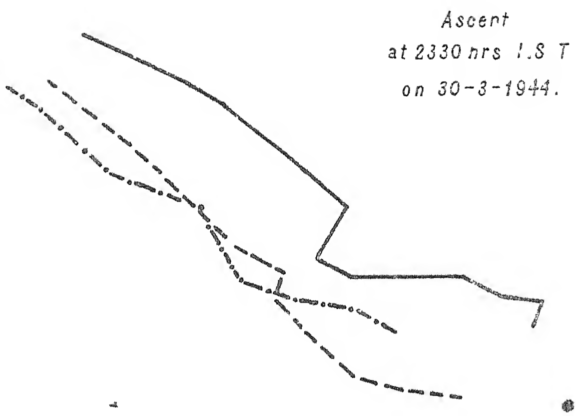

FIG. 3.

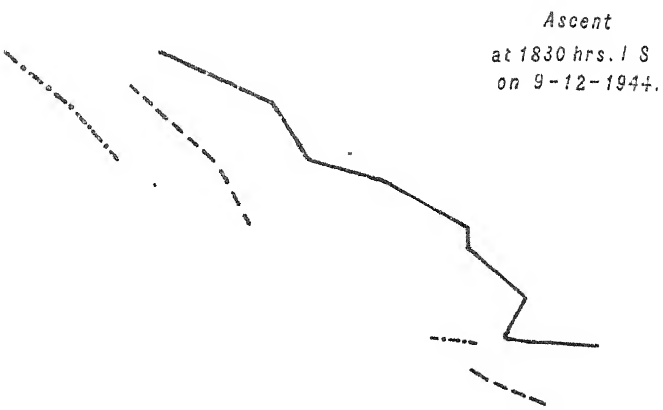

FIG. 4.

——— D.B.Curve ---- W.B.Curve -·-·- Normand Curve

BANGALORE

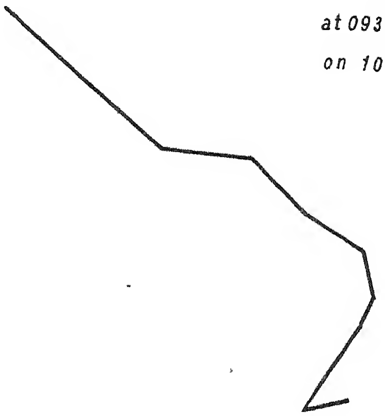

FIG. 5.

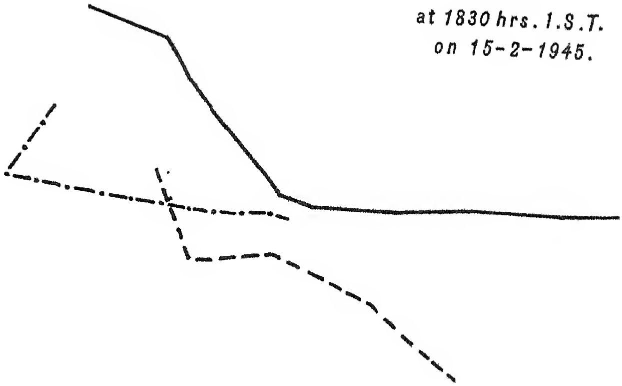

FIG. 6.

—— D.B. Curve ---- W.B. Curve -·-·- Normand Curve

BANGALORE

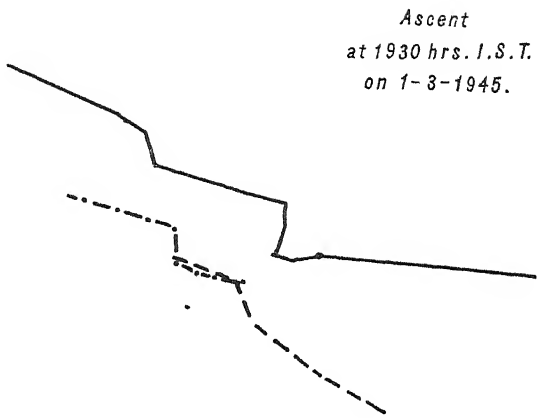

FIG. 7.

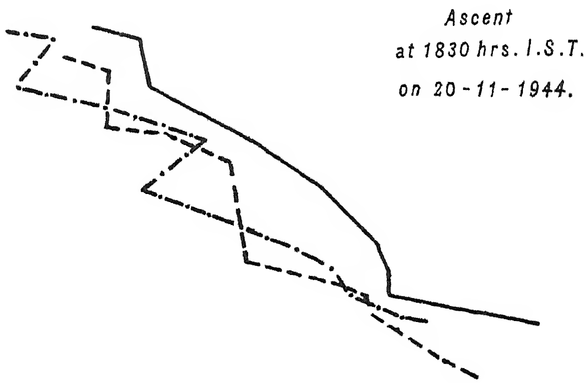

FIG. 8.

——— *D.B. Curve* - - - - *W.B. Curve* -·-·- *Normand Curve*

BANGALORE

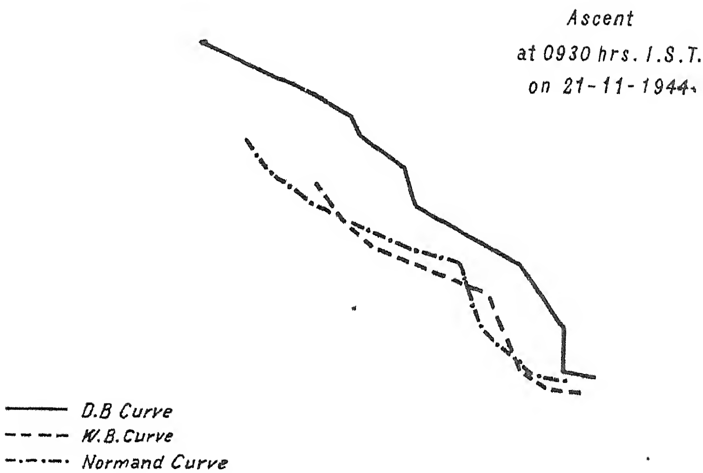

FIG. 9.

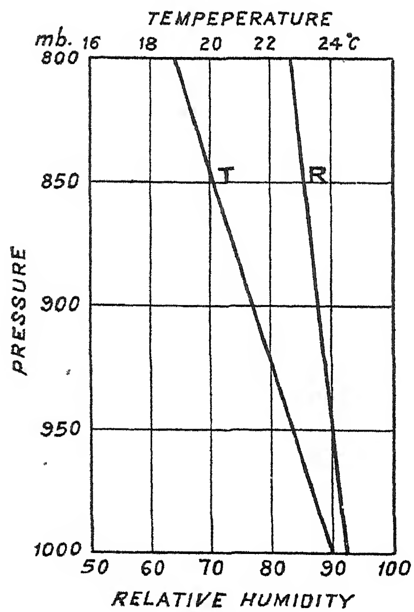

FIG. 10 (a).

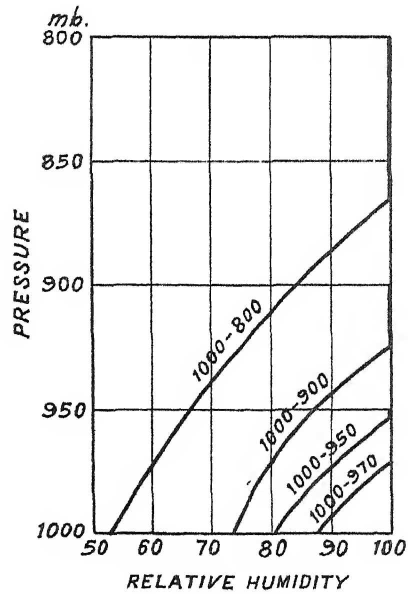

FIG 10(b).

D.B. Curve ---- W.B. Curve -·-·- Normand Curve

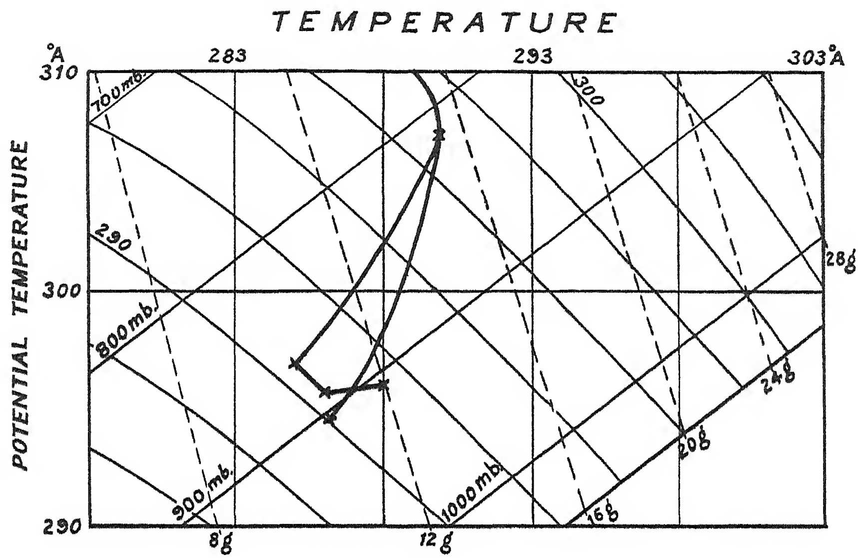

FIG. 11.

BANGALORE

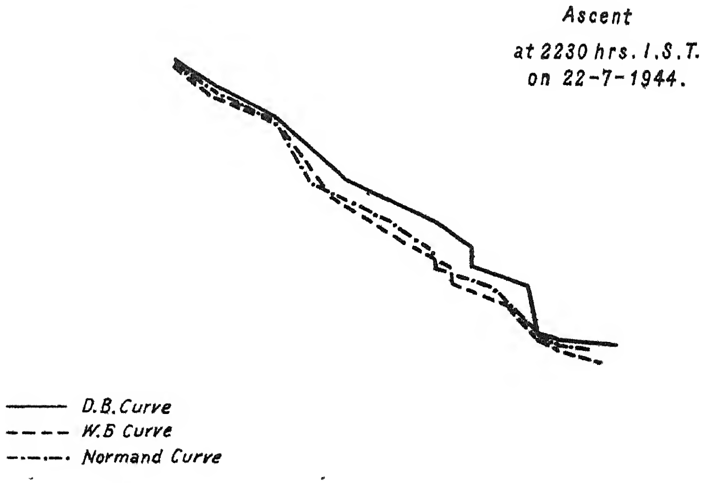

FIG. 12.

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Fog at Calcutta

By

K. C. CHAKRAVORTTY

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FOG AT CALCUTTA

BY

K. C. CHAKRAVORTTY.

(Received on 23rd April 1941)

Abstract.—Observations of fog at Alipore, Dum Dum and Bally have been analysed and the frequencies of foggy days computed. The foggy days have then been classified according to the type of fog. The distribution of times of onset and duration of fog and their association with sunrise have been discussed. An analysis of wind, cloud and temperature data before the onset of fog has been made to find out the conditions which are most favourable for the formation of fog. The note concludes with a discussion as to how a study of thermograph records of a station for the earlier part of a night may be helpful in the prediction of fog during the next morning.

Introduction.

Fog is an aviation hazard and forms an important subject for discussion of aviation interests. The object of this note is to discuss the characteristics of fog over Calcutta which is an important station in the Trans-India air route. An attempt has also been made here to find out how a study of local meteorological conditions in the evening may be helpful in the prediction of fog during the next morning.

For the purpose of the present investigation the observational data of Alipore, Dum Dum and Bally for the periods mentioned below were used :—

Place.		Position.		Period of record.
Alipore	.. Lat 22° 32′ N.	.. Long 88° 20′ E.	..	January, 1938 to December 1940.
Dum Dum	.. Lat. 22° 39′ N.	.. Long. 88° 27′ E.	.	December, 1938 to December 1940.
Bally ..	.. Lat. 22° 38′ N.	. Long. 88° 22′ E.		January, February, March and December of 1939 and 1940.

Alipore data for years earlier than 1938 were not used as the corresponding data neither for Dum Dum nor for Bally were available. In preparing the statistics for this note occasions of fog were recognised in accordance with the international specification and cases of mist or haze (visibility 4 or more) were not included.

Monthly Frequency of Fog. *Table I* below gives the average frequency of foggy days during the months October to April at Alipore, Dum Dum and Bally and the average monthly frequency of foggy days common to all these stations. It was found from a preliminary examination that fog does not occur in other months in this locality.

TABLE I.

Month.	Frequencies of foggy days per month.			Frequencies of foggy days per month.	
	Alipore.	Dum Dum	Bally.	Common to all these stations.	Common to Alipore & Bally
October	0	1	..	0	.
November..	3	1	..	0	..
December	5	3	2	1	1
January	12	4	10	1	8
February	8	5	7	3	5
March	5	4	6	2	4
April	2	0	..	0	.
Year	35	18	..	7	..

It is seen from the above table that the monthly frequencies are less at Dum Dum than at Alipore and Bally particularly in January and February. The frequency is maximum in January at Alipore and Bally and more or less uniform during December to March at Dum Dum. The industrial and domestic smoke which is more profuse at Alipore and Bally than at Dum Dum perhaps affords a larger number of nuclei for the formation of fog. It is interesting to observe that although Alipore, Dum Dum and Bally covers only a small area (about 35 square miles), simultaneous development of fog at all these stations is but a rare occurrence.

Classification of Fog.—From an examination of the meteorological conditions at the stations it has been found that the formation of fog was preceded by a fall of surface temperature due to radiation cooling. In some cases the dew point temperature remained steady, while in others dew point temperature was raised due to incursion of moist air, so that a comparatively small fall in dry bulb temperature was sufficient to initiate the formation of fog. The terms " radiation " and " advection fog " have been used in this paper to denote the former and the latter types respectively as explained above.

The percentage frequency of the occurrence of the two types of fog in different months is shown in *Table II* below :

TABLE II.

Month.	Frequency of occasions of fog irrespective of the place of Occurrence.		Common to all stations.	
	Radiation.	Advection.	Radiation.	Advection.
October	2	0	0	0
November ..	5	1	1*	0
December	11	3	0	1
January	22	11	0	1
February .. .	9	16	0	3
March	9	8	1	1
April	2	1	0	0
Year	60	40	2	6

*Common to Dum Dum and Alipore only.

It is seen from the above table that the annual frequency of advection type of fog is less than that of radiation type, but the advection fog is more frequent than radiation fog in February.

Time of Onset of Fog.—The frequency distribution of total number of occasions of fog observed at Alipore, Dum Dum and Bally in accordance with the times of onset is shown in *Table III* below :—

TABLE III.

	Number of occasions when fog began at :—									
	2100 to 2359 I.S.T.	0000 to 0259 I.S.T.	0300 to 0359 I.S.T.	0400 to 0459 I.S.T.	0500 to 0559 I.S.T.	0600 to 0659 I.S.T.	0700 to 0759 I.S.T.	0800 to 0859 I.S.T.	0900 to 2059 I.S.T.	Approximate time of sunrise. I.S.T.
October .. .	0	0	0	1	0	1	1	0	0	0534
November .	0	0	0	1	2	3	4	0	0	0550
December .. .	1	2	2	4	4	9	4	0	0	0609
January .. .	0	0	1	3	8	40	11	0	0	0620
February	0	2	3	7	13	19	4	0	0	0610
March	0	0	6	8	21	8	1	0	0	0546
April . ..	0	0	0	2	2	1	0	0	0	0517
Year .. .	1	4	12	26	41	18	25	0	0	..
%Frequency ..	0	·2	6	14	22	43	13	0	0	..

The most favourable time for onset of fog, as it is observed from the above table, is near about the time of sunrise.

Effect of Sunrise on Intensity of Fog.—*Table IV* below gives the % frequency of onset of fog before and after sunrise and the frequency distribution of the occasions when fog became thicker or thinner or continued with same intensity immediately after sunrise.

TABLE IV.

Percentage frequency of occasions when fog :				
		Began before sunrise but intensity :—		
Began after sunrise.	Began before sunrise.	decreased after sunrise.	increased after sunrise.	Constant after sunrise.
38	62	12	27	23

It is significant that when fog has begun before sunrise, it has sometimes a tendency to persist with undiminished intensity or even to intensify further for some time after sunrise. With sunrise in calm weather the saturated layer of air in contact with the earth surface which was originally at a temperature slightly lower than or equal to that of the layers immediately above it, is heated up more quickly than the layers above because the amount of solar radiation reaching the ground is much larger than that absorbed by the top layers of saturated air. This sets up convection from the ground level, as a result of which the lower layers in their upward motion cool down adiabatically and in mixing with the upper layers help further condensation there. Thus it is often observed that at day-break fog on lower ground gets thinner with a gradual intensification of fog in the upper layers. It is also noticed that with sunrise there is often a sudden thickening of fog at the lower layers extending up to high levels. This process of thickening is so rapid that any transport phenomena or temperature balancing processes have not time enough to be operative in such cases. It is quite possible that sun light produces more hygroscopic nuclei and thus creates a favourable atmosphere for enhanced condensation. With the advance of the day insolation takes the upper hand and fog at all the levels commences to disperse.

Duration of Fog.—It will be seen from *Table V* below that fog seldom persists for more than 3 hours, January and February being the months of maximum duration of fog.

TABLE V.

	Number of occasions when fog lasted for :—						
Month.	<60 mts.	60 to 119 mts	120 to 179 mts.	180 to 239 mts.	240 to 299 mts.	300 to 359 mts.	more than 359 mts.
October ..	1	1	1	0	0	0	0
November ..	7	1	2	0	0	0	0
December ..	8	8	6	1	2	1	0
January ..	17	28	12	1	5	0	0
February ..	7	18	9	7	3	3	1
March	10	8	9	8	0	0	0
April	1	4	0	0	0	0	0
Year . .	51	68	39	17	10	4	1
%Frequency .	27	36	20	9	5	2	1

Surface Wind Velocity before Onset of Fog.—The distribution of average surface wind velocity during three hours preceding the commencement of fog at Alipore is shown in *Table VI* below. Similar data for Dum Dum and Bally were, however, not available.

TABLE VI.

%Frequency of distribution of surface wind velocity.				
Calm.	1 M.P.H.	2 M. P. H.	3 M. P. H.	4 M. P. H. or more.
50	34	10	6	0

The normal value of surface wind velocity at Alipore during early hours of morning in cold season when fog is most prevalent varies from 1·5 to 3 m. p. h.*, but it is seen from the above table that on most of the foggy days the wind velocity does not exceed 1 m. p. h. before the onset of fog. In this connection it may be noted that if the wind movement is large enough to produce a turbulence in layers of air above ground, it will prevent the development of a surface temperature inversion.

Wind Direction at Lower Levels before Onset of Fog.—The early morning pilot balloon trajectories of Dum Dum for the days when fog began at Alipore, Dum Dum or Bally shortly after the routine time of early morning pilot balloon flight (0300 I.S.T.), as well as the pilot balloon trajectories of previous afternoons were examined with a view to find out the existence or nonexistence of southerly winds in lower levels before the onset of fog and the result is shown in *Table VII* below.

TABLE VII.

%Frequency of occasions when ·	Radiation fog.	Advection fog.	Any type
Wind was southerly in the early morning but not so in previous afternoon	6	76	34
Wind was southerly in the early morning as well as in previous afternoon	12	13	12
Wind was not southerly in the early morning but southerly in the previous afternoon . ..	20	7	11
Wind was not southerly in the early morning or in the previous afternoon	62	4	43

It is seen from the above table that on most of the occasions before commencement of advection fog southerly wind prevailed in lower levels in early mornings although there were no southerlies in the previous afternoons. The development of moisture laden southerlies in early mornings as mentioned above while changing the composition of air mass raised its dew point and created a favourable atmosphere for condensation.

Temperature and Cloudiness, before Onset of Fog.—The effect of heat loss by radiation from surface during the night in cooling the lower layers of air is important for the formation of fog. The *Table VIII* below shows the change in dry bulb temperature during three hours ending at the time of onset of fog on different occasions.

*V. V. Sohoni—Meteorological Normals of Calcutta Vol. XXV 1929, No. 1, Journal and Proceedings, Asiatic Society of Bengal.

TABLE VIII.

	%Frequency of fall of temperature :					
	<1°F.	1° to 1·9° F	2° to 2·9 °F.	3° to 3·9° F.	4° to 4·9° F.	5° F. or more
Radiation	13	47	25	5	5	5
Advection	36	47	17	0	0	0
Any type	21	48	22	3	3	3

Taylor found that among the factors which determine the amount of radiation cooling of lower air, wind speed and cloudiness are important. It has already been observed that calm or very light wind is favourable for formation of fog. In regard to cloudiness it may be mentioned that at night clear skies allow practically the whole amount of radiation emitted from the surface to escape into space but in cloudy nights clouds absorb a part of the outgoing radiation and reflect it back to the surface. Consequently clear nights are very suitable for radiation cooling of surface air. Solving the equation for the conduction of heat $\frac{ds}{dt}=K_1\frac{d^2s}{dz^2}$. .. (1)* (Where $S=\frac{dT}{dz}$) with the boundary condition $S=\frac{R_N}{\rho_1 C_1 K_1}$ at depth $Z=0$, Brunt obtained the following formula for radiation cooling of surface layers of the ground :

$$T=T_1-\frac{2}{\sqrt{\pi}}\times\frac{R_N}{\rho_1 C_1 \sqrt{K_1}}\sqrt{t} \quad \ldots .(2)$$

where

T_1=Initial temperature of the surface layer of the ground at the time $t=0$.
T=Temperature of the surface layer after time " t " secs.
R_N =Net loss of heat by radiation from the ground to the atmosphere.
ρ_1=Density of ground.
K_1=Specific conductivity of surface layer of earth.
C_1=Specific heat of ground.

The solution represented by the above equation corresponds to the case when the outward radiation is initially zero at the time " t "=0 and then instantaneously jumps up to the value R_N. A near approach to such a change is possible under the following circumstances :

1. With clear sky at the time of sunset.
2. With a sudden clearing of overcast sky during the course of the night.
3. With a rapid decrease of cloud amount with the advance of night.

As R_n of equation (2) is positive under each of the conditions mentioned above, cooling should be continued with advance of night and for an appropriate value of R_n the amount of cooling would be large enough to produce in due course a temperature inversion at the surface suitable for the formation of fog, unless the whole state of affairs is changed by the sudden development of an adverse meteorological condition in the mean time. It will be seen from *Table IX* below that in conformity

*Page 139 " Physical and Dynamical Meteorology " by David Brunt. (1944 edition).

with the above expectation either absence of cloud or a rapid diminution of cloudiness with the advance of night is favourable for the formation of fog.

TABLE IX.

Cloudiness mornings	%Frequency of cloudiness in afternoons and evenings preceding foggy				
	1600 I.S.T.	1700 I.S.T.	1800 I.S.T	1900 I.S.T	2000 I.S.T.
Clear ..	44	47	62	71	80
Partly cloudy (cloud 5/10 or less) .	35	36	28	24	17
Cloudy or overcast (cloud > 5/10)	21	17	10	5	3

Recurrence of Fog on Consecutive Mornings.—It is interesting that when fog has once occurred on a particular morning there is a tendency of its recurrence on a few more consecutive mornings. The statement shown in *Table X* below is relevant in this connection The cumulative effect of heat loss by radiation during consecutive nights, unless it is counter-balanced sufficiently during the intervening daylight hours, is perhaps responsible for this phenomenon.

TABLE X.

Month and Year.	Consecutive dates of fog at:		
	Alipore.	Dum Dum.	Bally.
January 1939 ..	12, 13, 17, 18, 19, 20, 21, 29, 30.	20, 21. 27, 28 ..	16, 17, 18, 19.
January 1940 ..	13, 14, 15, 17, 18, 19, 20, 28, 29.		8, 9, 10, 19, 20, 22, 23.
February 1939	5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16.	11, 12, 15, 16,	7, 8, 15, 16.
February 1940 ..	24, 25.	22, 23, 24, 25, 26,	22, 23, 24, 25.
March 1939 . ..	.	28, 29.	28, 29.
March 1940 . .	2, 3.	..	2, 3, 4; 9, 10.
December 1938 ..	25, 26, 27.	25, 26.	..
December 1939 ..	22, 23, 24, 25.	.	..
December 1940 .	7, 8.	..	..

Prediction of Fog.—In an attempt to find out a method for the prediction of fog the differences " dry bulb—wet bulb " at 17 hrs I.S.T. for a large number of days for Alipore, Dum Dum and Bally were plotted against the corresponding dry bulb readings. It was seen that the points representing the afternoons preceding foggy nights or mornings were scattered and no line could be drawn as in the case of Taylor's diagram. The dew point temperatures at 17 hrs. for several days at Alipore were then plotted against the corresponding minimum temperatures recorded during the following nights. It was found that fog occurred when the dew point temperature at 17 hrs. was either greater than or equal to or less than the corresponding minimum temperature,—a fact which indicates that the air mass at 17 hrs. often undergoes a change before the onset of fog. So for the purpose of fog prediction one has to foresee not only the probable change in D. B. temperature but also the probable change in the Dew Point during the course of the night. Whatever may be the local meteorological elements necessary for the condensation of fog, these elements are likely to set in at least a few hours before the condensation except in disturbed weather when a rapid change in meteorological condition

s not unlikely. So when 17 hrs synoptic chart does not indicate any possibility of development during the course of the night of elements adverse to the formation of fog, a study of actual character of variation of dry bulb and wet bulb temperatures during the earlier half of the night may be helpful for the prediction of fog during the later half. It is expected that at least for a few hours before the condensation of fog the difference " dry bulb—wet bulb " will gradually diminish till it will ultimately vanish with the commencement of fog. Let θ= difference D. B.—W. B. and t=time. Knowing the values of θ, $\frac{d\theta}{dt}+\frac{d^2\theta}{dt^2}$ near about mid night from the curves representing the relation between θ and t during the earlier half of the night one can find out whether "θ" is tending towards 0 after midnight and if so, he can also guess the interval of time since midnight to be required by a θ to attain the zero value. From an examination of the records of the Alipore thermograph for the years 1938-40 it was found that fog occurred on most of the occasions when the interval of time so guessed fell within the normal hour of minimum temperature. The occurrence of fog was found to be very rare on occasions when θ did not tend towards 0 or when the calculated interval of time mentioned above fell outside the normal hour of minimum temperature. In order to illustrate the above method of study, values of θ, $\frac{d\theta}{dt}$, $\frac{d^2\theta}{dt^2}$ and the calculated values of time interval since midnight for condensation to set in in respect of three consecutive days of each of the months December to February are shown in *Table XI*.

Table XI.

Date	θ at midnight, (°F).	$\frac{d\theta}{dt}$ near about midnight in °F/Hour.	$\frac{d^2\theta}{dt^2}$ near about midnight in °F/(Hours)².	Tendency of θ towards zero or not.	Interval calculated for θ to be zero.	Expected hour of zero value of θ (I.S.T.).	Normal hour of minimum (I.S.T.).	Whether fog occurred.	Time of onset of fog if any (I.S.T.).	Date of onset of fog if any.
27-12-38	3	+1	+1·0	No	.	.	0600	No. Fog.	..	..
28-12-38	2	0	0	No.	.		,,	,,	..	..
29-12-38	1	—1	0	Yes	1 hr	0100	,,	Fog.	0352	30-12-38
26-1-39	3	—0·5	0	Yes	6 hrs	0600	,,	,,	0527	27-1-39
27-1-39	2	0	0	No	.		,,	No. Fog	.	.
28-1-39	2	—1	0	Yes ..	2 hrs.	0200	,,	Fog.	0607	29-1-39
7-2-39	2	—1	0	Yes.	2 hrs.	,,	,,	,,	0452	8-2-39
8-2-39	4	—0·5	0	Yes	8 hrs.	0800	,,	No. Fog.	..	..
9-2-39	3	—2	—1·0	Yes.	2 hrs.	0200	,,	Fog.	0522	10-2-39

In conclusion I wish to express my thanks to Dr. P. K. Sen Gupta, D.Sc., Assistant Meteorologist, for his valuable suggestions and guidance throughout the work.

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The Mekran Earthquake of the 28th November 1945

BY

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THE MEKRAN EARTHQUAKE OF THE 28th NOVEMBER 1945.

BY

C. G. PENDSE

(*Received on 7th October 1946*)

Abstract.—This Note contains an account of the great Mekran Earthquake of the 28th November 1945. The seismic history of the area is outlined and the available seismometric data are summarised. The magnitude and the energy of the earthquake are calculated and it is found that, so far as the magnitude is concerned, this earthquake is not particularly important in comparison with other great earthquakes. The important feature of this earthquake is the seismic seawave associated with it. The available information regarding the effects of the seawave has been summarised. The isoseismal lines for the earthquake, based on field reports, are shown in a map and inferences are drawn from them. Additional information, especially about the two islets reported to have been thrown up by the earthquake, is given.

Introduction.

The object of this Note, which consists of six sections, is to give a brief account of the earthquake of 1945 November 28 which, with its epicentre under sea near the Mekran Coast, was attended by a disastrous seismic sea wave. Section 1 gives a sketch of the earthquake history of the region over which it was felt. Section 2 gives a summary of the available seismometric information. Section 3 gives the seismometric estimate of the magnitude and energy of the earthquake. Section 4 contains a map showing the isoseismal lines for the earthquake and the conclusions drawn from it. Section 5 contains an account of the seismic sea wave mentioned above. In section 6 is given some additional information regarding the shock.

1. The seismic history of the area of the Mekran earthquake.—The earthquake which shook the Mekran Coast, Baluchistan, Sind and parts of the Punjab in the early hours of the morning of the 28th November 1945 was by no means a rare event for that portion of the globe. Earthquakes have been known to occur in that area in the past, and we mention below some important ones.

1819 June 16	Cutch.
1892 December 20	Chaman, Baluchistan.
1909 October 21	Baluchistan (Kachhi).
1931 August 27	Mach, Baluchistan.
1935 May 31	Quetta.

During the last few years there have been some earthquakes having epicentres near the Mekran Coast and Karachi. Some of them are listed below :—

Time (G.M.T.)		Epicentre	
1938 February 4	.. .. ..	25·5° N.,	Mekran Coast
00h. 19·0m.	.. ..	63·5° E.	
1938 September 2	.. .. ..		Ormara.
20h 29·0m.	.. ..		
1940 January 7 ..	.. .. ..	26·0° N.,	Near Mekran Coast.
00h. 1·9m.	.. ..	63·0° E.	
1941 October 29	.. .. ..	26 6° N.,	Baluchistan.
13h 13m.	.. ..	63·5° E.	
1942 July 3	.. ..	24·5° N.,	Felt at Karachi.
02h. 50m 30s.	.. ..	65 5° E.	
1942 July 4	.. .. .. Near	25° N.,	Baluchistan.
08h. 46m. 20s.	.. ..	67° E.	
1943 February 6	.. .. ..	24·2° N.,	Near Pasni.
02h. 35m. 48s.	.. ..	62·6°E.	

An increase in the seismic activity in this region is noticeable in recent years, since, according to the International Seismological Summary, there are only about half a dozen earthquakes with epicentres in this area, for the period 1913-34. This relative increase cannot and should not, however, be used to make a forecast of the earthquake activity in the region in the coming years.

2. A summary of the available seismometric data.—The earthquake of the 28th November 1945 was, as recorded by the seismographs throughout the world, one of great intensity. It is not possible to locate the different phases of the earthquake in the available Indian seismograms ; in the case of photographic records of Milne-Shaw seismographs, the traces were invisible for some time after the first impulse ; in the case of mechanically registering seismographs, the motions were so large and rapid that the onsets could not be marked with certainty and accuracy. The epicentre and the origin time of the earthquake have been determined from the times of the onsets of the P-phase at the different stations. The data are summarised below :—

Station	Time of commencement (G.M.T.)
Bombay	eP_N = 27d. 21h. 59m. 19s.
	iP_E = 27d. 21h. 59m. 20s.
New Delhi	iP_N = 27d. 21h. 59m. 54s.
	iP_E = 27d. 21h. 59m. 56s.
Calcutta	iP_E = 27d. 22h. 02m. 00s.
Hyderabad (Deccan)	iP_N = 27d. 22h. 00m. 31s.
Kodaikanal	iP_E = 27d. 22h. 01m. 19s.

Origin time : 27d. 21h. 56m. 40s. G.M.T. Epicentre : 24·2°N., 62·6° E. The epicentre is under sea near the Mekran Coast and is about 75 miles away from Pasni.

3. The magnitude and energy of the earthquake.—From the available seismograms, the Milne-Shaw north-south component seismograms of Bombay and New Delhi were useful.

The following method for calculating the magnitude of the earthquake was used for the data of each station.

A' (the maximum amplitude of the recorded trace in millimetres) and T (the corresponding period of the ground movement in seconds) were measured from the seismogram. a (the true ground displacement in microns corresponding to A') was computed (using the appropriate dynamic magnification factor). Then the values of a and T were substituted in the equation

$$A = \frac{V}{1000\,[(u^2-1)^2+4h^2u^2]^{\frac{1}{2}}}\,a,$$

where $V = 2800$, $u = \dfrac{T}{T_0}$, $T_0 = 0{\cdot}8$ secs., $h = 0{\cdot}8$.

A gives the amplitude (in millimetres) of the trace recorded at the station by a standard torsion seismometer (a seismometer having the constants prescribed above) corresponding to A'. M (the magnitude of the earthquake) was then calculated by means of the formula

$$M = \log A - \log A_0,$$

where $\log A_0$ depends only on $\triangle$ (the epicentral distance of the recording station). A comprehensive discussion of the question of the magnitude and energy of earthquakes is given in section V of B. Gutenberg and C. F. Richter's paper "On Seismic Waves (Third Paper)", Gerlands Beiträge zur Geophysik, vol. 47, pp. 73—131, 1936 ; and the value of $\log A_0$ corresponding to an assigned value of $\triangle$ can be read off from Fig. 6 on p. 120 of the paper.

After calculating M for both the stations and taking the average of the two values the energy of the earthquake was calculated by means of the formula

$$E = E_o \, 10^{2M}$$

where the value of E_o has been empirically taken to be 10^8 ergs by the above authors.

The results of the calculations are given in the following table :—

Station.			A' mm.	T sec.	a μ	A mm.	log A	Δ_o	log A_o	M
Bombay	..	..	95	18	950	5 3	0·72	11·0	—5·9	6·6
New Delhi	..	..	100	28	2220	5·1	0 71	13·9	—6·0	6·7
						Mean value of M = 6·65				

Hence

$$E = 10^8 \times 10^{2 \times 6.65} \text{ ergs}$$
$$= 10^8 \times 10^{13.3} \text{ ergs}$$
$$= 10^{21.3} \text{ ergs.}$$

Thus the estimate of the magnitude of the earthquake is about 6·7 and that for the energy of the order of 10^{21} ergs. From Gutenberg and Richter's tables giving their estimates of selected shocks, we find the following earthquakes whose magnitudes are approximately 6·7, *i.e.*, the magnitude of the Mekran earthquake.

Date			Epicentre in
1932 July 12	..	..	.. Gulf of California
1932 December 7	..	..	.. Mexico
1934 January 28	..	..	.. Mexico
1934 May 4	..	..	.. Alaska
1934 July 28	..	..	.. Alaska
1934 November 30		..	.. Mexico

For purposes of comparison of the earthquake under consideration with others as regards magnitude, the following list of a few selected earthquakes is given from the material provided by Gutenberg and Richter.

Date			Epicentre in				Magnitude
1905 April 4	..	..	.. Kangra, India	..	..	..	7¾
1912 May 23	..	..	.. Burma	..	..	..	8
1912 August 9	..	..	.. Turkey	..	..	..	8
1922 November 11	..	..	.. Chile	..	..	..	8·4
1923 September 1	..	..	.. Japan	..	..	..	8·1
1933 March 2	..	..	.. Japan	..	..	..	8·3
1934 January 15	..	..	.. Bihar	..	..	..	8·2
1935 May 30	..	..	.. Baluchistan (Quetta)		..	..	7·7

It is seen, therefore, that in comparison with prominent large earthquakes of the past, the Mekran earthquake was not particularly important so far as its magnitude is concerned. Its importance and interest are due to the seismic sea wave associated with it.

In contrast with the Quetta earthquake, which caused great destruction locally, this earthquake, by itself, did little damage ; the damage was due to the seismic sea wave.

4. The area affected by the earthquake.— The places in India most distant from the epicentre where the earthquake was experienced were Dera Ismail Khan and Montgomery. The distribution of the intensity of the ground motion due to the earthquake is shown in the accompanying map showing the isoseismal lines.

From the elliptical isoseismal lines, we can draw the following conclusions :—

(1) The intensity of the shock falls off much less rapidly along the major axis than along the minor axis.

(2) The main direction of the distribution of the shock is almost parallel to the north-east through the epicentre.

(3) The areas in square miles for the different intensities can be approximately indicated as follows* :—

Intensity (Rossi-Forel Scale)	Area (Thousand square miles)	
> 10	11·5	
		21·5
> 8	33	
		55
> 7	88	
		352
> 5	440	

(In making the above estimates of the areas the following assumption has been made: —

The portions of the isoseismal lines in the region under sea are such that the complete isoseismals are symmetrical about the north-west direction through the point 24·3°N., 63°E., which is approximately at the centre of the system of isoseismals.)

5. **The sea wave associated with the earthquake.**—Level changes of as much as 50 feet have been recorded in connection with fault movements causing earthquakes. Sea waves are produced whenever such changes, or extensive landslides, occur in the sea bed. Owing to their association, in most cases, with earthquakes, these waves are called seismic sea waves or " Tunamis " and, popularly though erroneously, Tidal Waves.

Not all land earthquakes are accompanied by surface fault movements. Similarly, not all submarine shocks are accompanied by changes in the level of the sea bed and the resulting seismic sea waves. Actually, it is found that the number of submarine earthquakes, which cause destructive sea waves is very small.

The earthquake in question was attended by a seismic sea wave which affected the whole of the Arabian sea-board. Karwar, about 1,000 miles away from the epicentre, was the most distant place at which the ' tidal ' wave was reported to have produced tangible effects. At Karwar, the wave flooded the creeks and inlets, and boats anchored in the harbour were cut off from their moorings, though no damage was done. The available information regarding the wave is summarised below.

Mekran Coast.—Pasni, an important trading centre along the Mekran Coast and distant about 75 miles from the epicentre, was overwhelmed by the wave, there being serious loss of life and property. At about 4 A.M. a wave was noticed but it did not come inland. At about 7-15 A.M. another wave swept over the town and caused widespread havoc. The height of this wave has been estimated variously from 40 ft. to 50 ft. Serious loss of life and property was also caused at Ormara (about 130 miles away from the epicentre) and in several coastal villages. Large quantities of fish were washed inland on the coast.

Karachi.—Karachi, which is at a distance of about 275 miles from the epicentre, experienced waves affecting the harbour at 5-30 A.M., 7 A.M., 7-50 A.M. and 8 15 A.M. The last one was the largest and its height was estimated to be 4½ ft. above normal. Fortunately, the times at which the waves occurred were different from the times of high tide at Karachi on that day, namely, 06h. 37m. and 19h. 45m. I.S.T. The last wave, which was the largest, is reported to have produced a strong ebbing current of between 4 and 5 knots, apparently during its recession. The wave caused damage in the Karachi harbour and loss of life and property along the Karachi coast.

*The figures in the last column give the areas (in thousand square miles) of the portions between the successive isoseismals.

Bombay.—Bombay, 750 miles away from the epicentre, experienced a wave at 8-15 A.M., its height being $6\frac{1}{2}$ ft. There was some loss of life. Fortunately, however, the times of high tide for the day were 06h. 58m. and 20h. 12m. I.S.T.

6. Additional information regarding the earthquake.—It has been reported in the Press that two rocky oval islets were thrown up by the earthquake about 180 miles west-south-west of Karachi. The islets are about 3 miles apart, one rising about 30 feet above the water and the other about 100 feet ; the former is about one and a half square miles and the latter about a square mile. When the officer commanding the Indian naval ship *Hindustan* first saw the new islets, he examined his charts and then sent out the following signal : "Two uncharted islets have appeared in the approximate position of 25 degrees and 7 minutes north, and 64 degrees and 15 minutes east". A correspondent of the Associated Press of India who was on the ship has reported that, according to the information gathered from the villagers, immediately after the earthquake a loud rumbling noise was heard and was followed by a huge sheet of flame and columns of smoke and that these were followed by the seismic sea wave.

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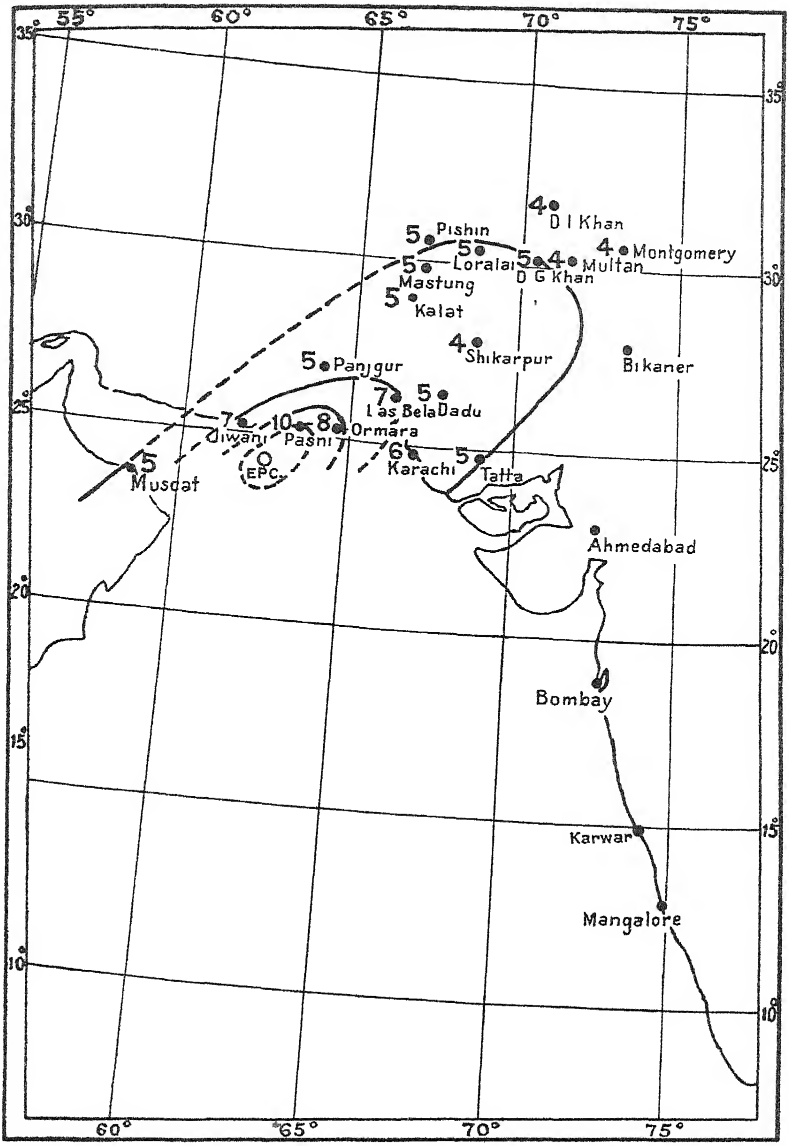

Isoseismals of the earthquake –
of 1945 Nov. 27 d. 21 h. 57 m. (approx.) G.M.T.

G. P. Z. P. POONA, 1947

DGO. 19. X. 126
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Frequency of Micropulsations and their variation at Alibag

BY

S. K. Chakrabarty

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FREQUENCY OF MICROPULSATIONS AND THEIR VARIATION AT ALIBAG

BY

S. K. CHAKRABARTY

(*Received on 9th October, 1946*).

Abstract.—Micropulsations are recorded as a distinct type of short period oscillations in the magnetograms which record continuous variations in the geomagnetic field. With a view to study the frequency of occurrence of these short period oscillations at Alibag and the possible nature of their variations with seasons and sunspot activity, the geomagnetic records for the years 1937, 1938 1940, 1941, 1944 and 1945 have been examined and the results have been analysed.

It appears that the diurnal variation of the frequency of micropulsations has a sharp maximum round about the local midnight and the position of the maximum as well as its intensity varies with the sunspot activity. The seasonal variation, however, is not very marked. The correlation between the frequency of micropulsations and the international magnetic character figure has been examined. The results show the possibility of an attenuation of the frequency by the magnetic activity. The 27-day recurrence tendency has also been examined. While in 1944 it was very marked it was not so in the other years.

The results obtained have been compared with similar results for observatories at high latitude, *viz.*, at Tromso and Sodankyla. A table showing a few details of some characteristic pulsations has been given which when compared with the recorded pulsations, if any, during the same period, in other observatories will possibly lead to a determination of the nature and position of the ionospheric current system with which these micropulsations are possibly associated.

Micropulsations are a special type of short period oscillations which are recorded at different times in the magnetograms recording continuous variations of the geomagnetic field. They occur during storms, when however, they are mixed up with the large variations of the magnetic elements and also on quiet periods. The periods of such oscillations, given by the interval of time that elapses between two consecutive crests in the waves, vary between a few seconds to as much as 5 to 6 minutes. In ordinary magnetograms where the time scale is about 4 minutes to 1 mm. short period oscillations appear as serrations, but those with longer periods appear with a characteristic and easily distinguishable series of sinusoidal waves. In such cases the period of the wave remains more or less constant during the interval they are recorded but the amplitude in some cases increases gradually to a maximum and then gradually decreases until it disappears, although in some cases the amplitude remains practically unchanged during a considerable period of its existence. Several authors[1] have studied the different properties and their variations and have designated them as " Micropulsations " or " Giant Micropulsations " or " Sinusoidal Oscillations ". Most of the results published relate to those recorded in different observatories at high altitudes. While in some features they vary from place to place, yet it is

observed that the frequency of these micropulsations has a maximum near about the local midnight and a minimum near about three hours before local noon. The ratio of the numbers at the maximum to those at the minimum, however, varies widely with the geographical positions of the observatories Moreover it has been noticed that in many cases they are not recorded simultaneously at two stations which are quite close to each other and as such are considered as a local phenomenon as opposed to the world-wide nature of the magnetic storms and disturbances. The regularity in the form of these pulsations may suggest that they are due to resonance effects in the instruments. This is ruled out by the fact that the magnets in the variometers have a much shorter free oscillation period which usually varies between 5 and 15 seconds. It is the purpose of the present paper to study the occurrence, frequency and variations of these micropulsations at Alibag ($\varphi=18°\cdot 6$, $\lambda=72°\cdot 9$).

On the ordinary time-scale, viz , 15 mm. for an hour, it is not possible to find out the very short period fluctuations, but those with period equal to or more than 1 minute can be easily recognised. Pulsations of shorter period can also be recognised if the double amplitude is about 3γ or more. In the present paper we have thus considered only those pulsations whose double amplitude is either equal to or more than 3γ or whose period is equal to or more than 1 minute. It has been noticed in the Alibag magnetograms that in practically all the cases where D and V variometers have recorded a pulsation, a similar pulsation has also been recorded by the H variometer but the converse is not always true. Moreover the V variometer at Alibag being very sensitive the traces on some days have a jagged appearance all throughout the day. Hence for the sake of homogeneity in the data we have counted only the micropulsations recorded in the horizontal intensity magnetograms and it is highly probable that by doing so practically all the micropulsations have been taken into consideration. At Alibag sometimes even on quiet days during the day time irregular vibrations are recorded in the H trace continuously for a long period. Moreover in the post-perturbation period after a magnetic storm of moderate intensity, the H trace sometimes continues to record oscillations of small amplitude, though in most cases their period is large. Since it is our purpose to study the micropulsations as an isolated phenomenon, we have considered only those micropulsations which are surrounded by quiet periods or at least those which cannot be associated with any effect of disturbance, immediately preceding it. Such pulsations are shown in *Figs. 1 and 2*. Visually such pulsations can be divided into two groups depending upon the variations of their amplitudes. The first group in which the amplitudes do not vary appreciably during the whole period of pulsations have been classed in this paper as A and the other group where the amplitude gradually increases to a maximum value and then decreases to zero have been classed as B. It is found that about 40% of the total number of micropulsations recorded in a year are of the type B. The total duration of such micropulsations varies between 4 minutes to about an hour There are a few cases where such pulsations have continued for more than two hours which can also be associated with a feeble disturbance. Such micropulsations have, however, not been counted but I have given some details of some such oscillations in *Table 3* so that magnetograms of other observatories may be examined for these periods in order to study whether they are really associated with any storm or are real micropulsations.

For studying the variations of these micropulsations also with seasons and sunspot activity I have examined the magnetograms for the years 1937, 1938, 1940, 1941, 1944 and 1945, where the first two years include a period of maximum sunspot activity and the last two that of minimum activity. In *Fig. 4*, I have plotted the frequency of these micropulsations during each hourly interval centred at full hours

of G. M. T. for the whole series consisting of groups A and B. The figure shows the mean diurnal variations of the occurrence of these pulsations It appears that near the sunspot maximum the maximum frequency lies at 18hrs. G. M. T. which then gradually shifts towards later periods with the decrease of sunspot activity and for the years round the sunspot minimum the maximum occurs at about 20 hrs. G. M. T. Since 19hrs. G. M. T. practically coincides with the local midnight, it is clear that the maximum frequency of the pulsations occur within about 1 hour of the local midnight although it occurs before the midnight during the sunspot maximum years and after the midnight during the sunspot minimum years. A similar shift in the time of occurrence of the maximum has also been noticed in the data of Sodankyla by Sucksdorff[4]. The maximum ordinate of the frequency curves also diminishes with the increase of sunspot activity. Besides these there seems to be little variations of the frequency with sunspot activity. The ratio of the frequency of pulsation during the three hours centred at local midnight to that during the three hours centred about the minimum which is at about 3 hrs. G. M. T. is about 5·0 in the sunspot maximum years, 11 during years of medium activity and 46 in the sunspot minimum years. The corresponding figure for the whole group of six years under consideration is 11. The similar figures for Samoa and Potsdam are 4·2 and 110 respectively. The minimum in the diurnal distribution, however, occurs in the forenoon between 2-4 hrs. G. M. T. The diurnal variation in that of B group alone is more or less similar to that of the total number consisting of both A and B and there is no marked difference between their variation.

In *Table 1*, I have given the frequency of these pulsations during the different months of the different years. It shows that there is no consistent variation with seasons. During the years 1937, 1938 and also in 1940 their distribution over the seasons was fairly uniform whereas during 1944 they were much more frequent in the solsticial seasons as compared to the equinoctial season. Harang[3] has shown that the annual curve at Tromsö indicates two maxima near the exquinoxes but the analysis of Rolf[1] shows that at Abisko the autumn maximum was very prominent but the spring maximum was lacking though Abisko is only about 150 km. away from Troms .

TABLE 1.

Annual and seasonal variations of Micropulsation frequency in different years.

	J	F	M	A	M	J	J	A	S	O	N	D	d-solstice	e-equinox	j-solstice
1937	17	10	13	12	15	7	5	17	13	5	5	9	41	43	44
1938	6	9	17	7	8	10	6	20	7	8	12	12	39	39	44
1940	4	12	8	15	15	3	9	10	6	6	6	11	33	35	37
1941	4	9	4	6	6	8	12	16	7	8	3	8	24	25	42
1944	8	17	6	5	13	12	12	9	5	6	13	7	45	22	46
1945	10	7	5	2	4	7	5	7	17	3	14	6	37	27	23

The monthly values, however, vary in a way similar to the variation of the monthly mean international character figure C. A rise in the value of C (mean monthly value) from month to month is generally associated with a fall in the monthly value of the frequency of the pulsations and vice versa, though the degree of variation is not always equivalent. This possibly means that these pulsations are equally frequent in all seasons but they are sometimes masked by the ordinary disturbances and hence with the increase in disturbance their frequency decreases. To study whether there is any connection between mean magnetic activity and the occurrence of these pulsations, I have examined the correlations between the monthly mean character figure and the number of days every month in which pulsations were recorded. The 24 months of 1937 and 1938 have been considered in one group and those of 1944 and 1945 have been considered in another group The correlation coefficient is negative in both cases but its magnitude is ·31 in the sunspot maximum years and ·48 in the sunspot minimum years. This possibly shows that the pulsations are not directly connected with magnetic activity but the latter indirectly affects the total number of pulsations by suppressing some of these pulsations under the greater fluctuations caused by magnetic disturbances.

The days of pulsations were examined to find out whether there was any definite period after which they re-appear. It was found that in a large number of cases they re-appear on consecutive days and sometimes at exactly the same hour, particularly when it is round about the local midnight. Johnston[2] has found that the very short period pulsations have a marked 27-day recurrence tendency. In the present case it was found that generally only 30 to 40% of the recorded pulsations show a 27-day recurrence tendency. In *Table 2*, I have shown dates on which pulsations showing recurrences were recorded during 1944, on which recurrences were maximum among the years considered in the present paper.

TABLE 2.

27-day recurrence tendency of Micropulsations at Alibag in 1944.

Months.	Initial dates and dates of recurrence of Micropulsations in 1914.																	
January	..	..	9	..	..	..	..	24	..	..						2		
February	..	..	5					20		..	23	..	26	..	..	29	3	4
March ..	.	..	3	..				18	..	..	21	..	24	..	..	..	1	2
April ..	..	..	..	..				..	15	..	..	..	..	..			..	25
May ..	..	..	23	24				..	12	..	14	15	17	18	..	..	21	22
June ..	..	..	..	20	3			7	8	..	10	11	..	14				..
July ..	..	..			27			..	5	..	7	8						15
August ..	..	..			23			27	1	..	..	31	..	..				..
September	..	..			19			..										7
October	..	..		2	..	18		20	..	22	..	..	..	..	..	28		
November	..	..	..	29	..	14		16	..	18						24		
December	..	..				11												

The variation of the total number of pulsations recorded in a year with sunspot activity is also not very marked. It appears that during the maximum sunspot years the total number recorded at Alibag is somewhat greater than the number recorded during the minimum sunspot years or during years of moderate activity. Harang[3] has however, shown that at Tromsö ($\varphi = 69°·7, \lambda = 18°·7$) micropulsations were

frequently recorded during the International Polar Years, 1932-33, which is around the sunspot minimum but during 1937-38 the number recorded in the northern part of Scandinavia and Iceland was very low. It is interesting to note that at Tromsö no pulsations of normal character were recorded between March and November 1938, though Sucksdorff[4] has reported that during this period as many as ten pulsations were recorded at Sodankyla ($\varphi = 67°\cdot4$, $\lambda = 26°\cdot6$) although the two stations are quite near to each other. Alibag magnetograms were examined for the same days of 1938, but no trace of pulsation could be noticed. La Cour[5] has reported that a pulsation was recorded on April 22, 1938, at Copenhagen, but from the paper of Sucksdorff it appears that if at all this can only be associated with one recorded at Sodankyla about two hours later. This was not recorded at Alibag. On the other hand there are instances when micropulsations during very quiet period have been recorded at distant stations. In *Fig. 1*, I have shown the record of a pulsation which occurred between 1500 hrs. to 1520 hrs. G. M. T. on the 26th May 1942 during very quiet period which was recorded simultaneously at Alibag and Dehra Dun* though the two stations are more than 1600 km. apart. A number of similar examples are also available. These facts show that all the pulsations recorded cannot be considered as a local phenomenon. La Cour[6] has also classified the recorded oscillations of the magnetic elements at Copenhagen during 14hrs-18hrs G. M. T. on March 1, 1942 as a giant pulsation. This was recorded also at Alibag and Dehra Dun and during this period the maximum double amplitudes recorded at Alibag for D, H and V were $0'\cdot7$, 18γ and 4γ respectively. In *Fig. 3*, I have shown the records of Alibag and Dehra Dun for this pulsation. But this is associated with the storm of great intensity which had a sudden commencement at about 7h. 27m. G. M. T. on March 1. But this is certainly of a different type and is associated with different causes than the micropulsations discussed above, which usually occur during quiet periods and cannot be associated with any disturbance either before or after its occurrence. In *Table 3*, I give some details of a number of pulsations which have been recorded at Alibag during quiet periods and was quite significant for their continuation for a long period. It would be interesting to examine whether such pulsations are a local

TABLE 3.

Date.	Time of start.	Time of end.	Max. double amplitude. H	Max. double amplitude. V	Max. double amplitude. D	Period.	Remarks.
	G. M. T.	G. M. T.	γ	γ	Min.	Min.	
13-10-37	0430	0920	9	4	0·5	6	
17-1-38	0640	1150	13	5	0·67	4	Probably associated with a disturbance which commenced suddenly at 1835 hrs. on the 16th.
15-9-41	0620	0820	6	2	0·3	4	
7-9-44	0930	1430	5	..	0·1	2	

* I am indebted to the President, Survey Research Institute, Dehra Dun, for kindly sending me the magnetograms of the Dehra Dun Observatory.

phenomena or they have also been recorded in observatories at higher latitudes. In that case a measure of the variation of the amplitudes and periods, if any, with the geographical positions may possibly lead to some indication as to the nature and position of the ionospheric current with which these micropulsations are associated.

Harang[3] has stated that during the appearance of the giant pulsations in the magnetic elements on December 28, 1938, the echo record also indicated pulsations in the ionospheric region at the height of 650—800 km. with exactly the same period as that of the pulsations recorded in the magnetograms. He has suggested that the cause of these pulsations is situated at a high level in the ionosphere. The suggestion is interesting but requires careful examination and also an analysis of a large mass of similar data before it can be accepted. It is unlikely that the cause of these pulsations can be at such high level in the atmosphere since in that case it should always be simultaneously recorded in adjacent stations which is found to be otherwise in a number of cases.

The results obtained in the present paper show that these micropulsations occur uniformly throughout the year and also do not vary appreciably in number with sunspot activity. The diurnal as well as annual variation observed may also be affected by the fact that the micropulsations are sometimes masked by the irregularly appearing perturbations due to the magnetic disturbances and as such escape detection. The magnetic activity will possibly attenuate rather than accentuate the total number of pulsations in a year and also their variation.

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[4] E. Sucksdorff, (1939) Terr. Magn. **44**, 157.

[5] D. La Cour, (1938) Terr. Magn. **43**, 199.

[6] D. La Cour, (1942) Terr. Magn. **47**, 265.

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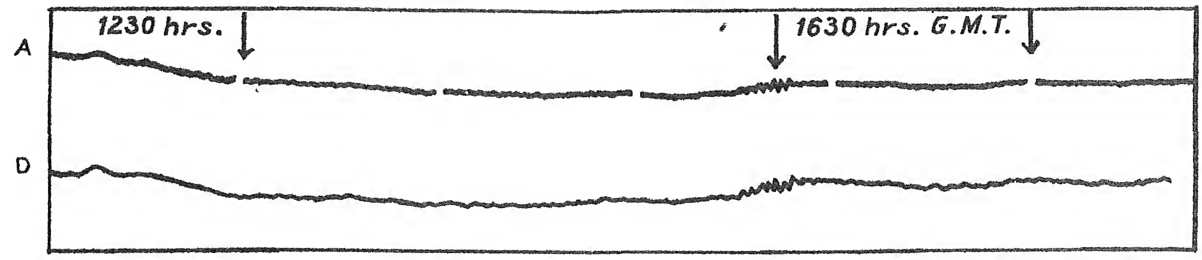

Fig. 1. Micropulsations recorded simultaneously at Alibag (A) and Dehra Dun (D) on 26th May 1942.

Magnified Reproduction.

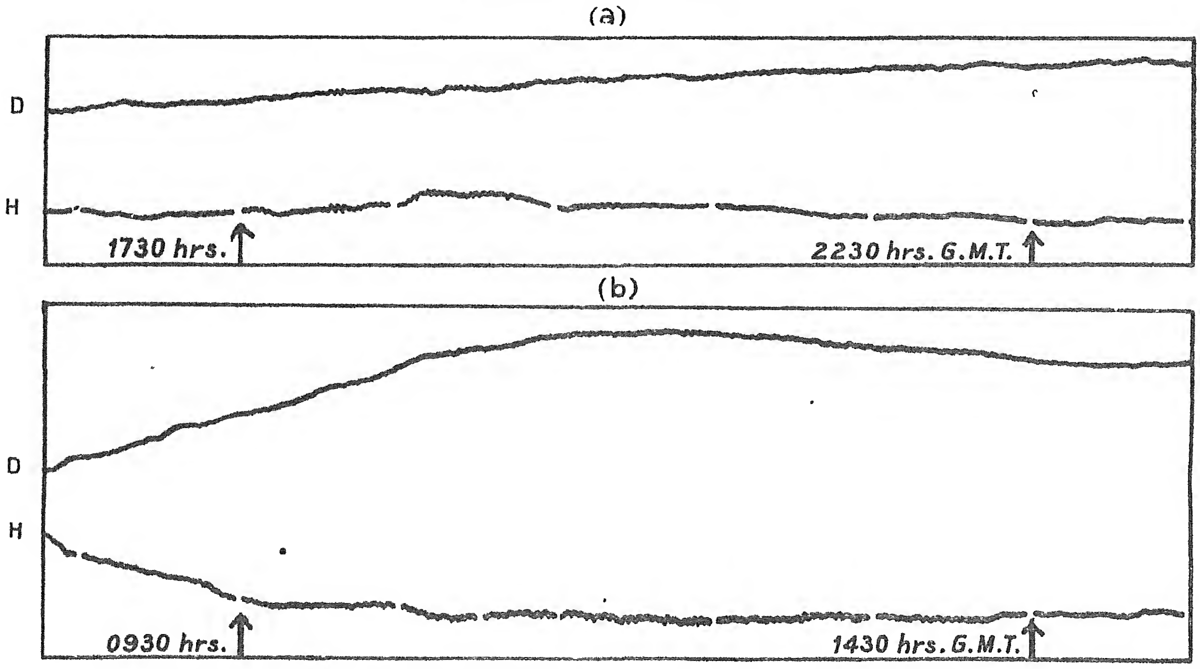

Fig. 2. Records of pulsations continuing for a long period
(a) Alibag D and H for 16th May 1944.
(b) Alibag D and H for 7th September 1944.

Magnified Reproduction

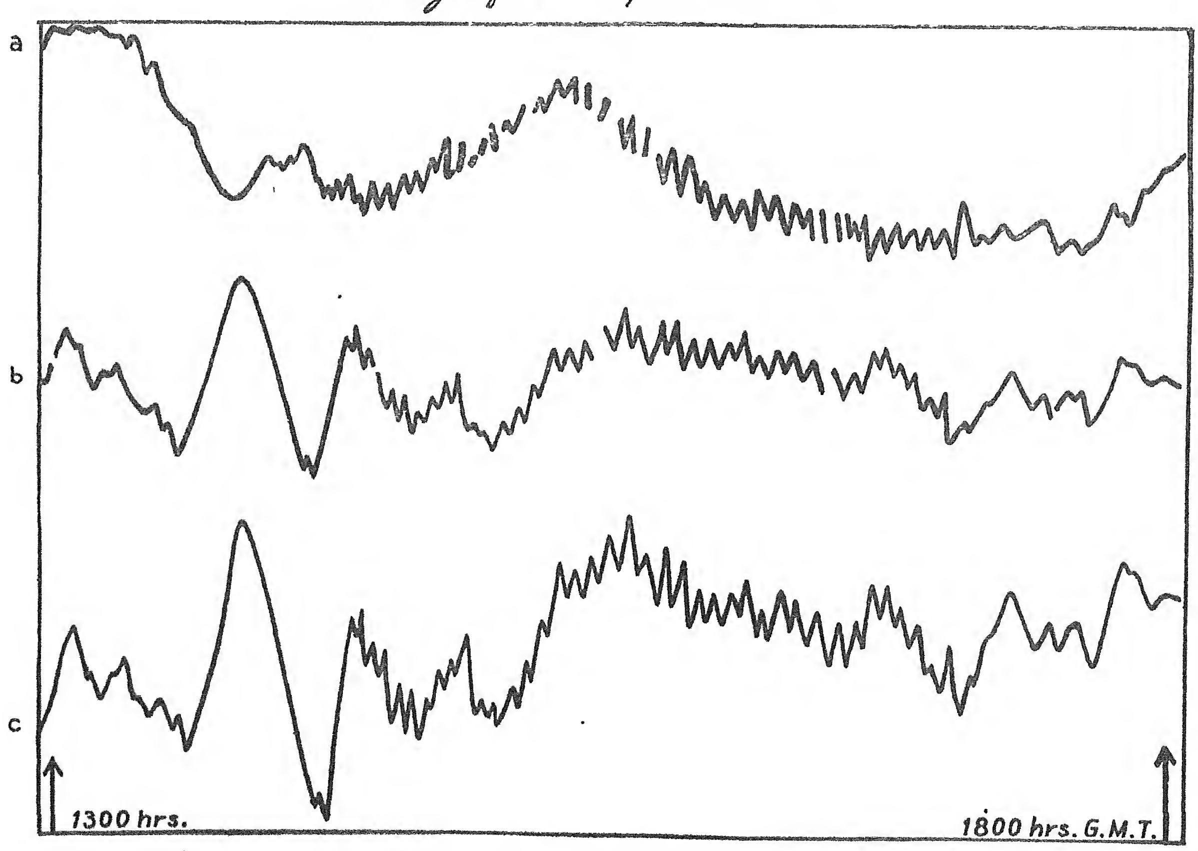

Fig. 3. Giant pulsation recorded between 1400 hrs. to 1800 hrs. G.M.T. on 1st March 1942. (a) Alibag D. (b) Alibag H. (c) Dehra Dun H.

Magnified Reproduction.

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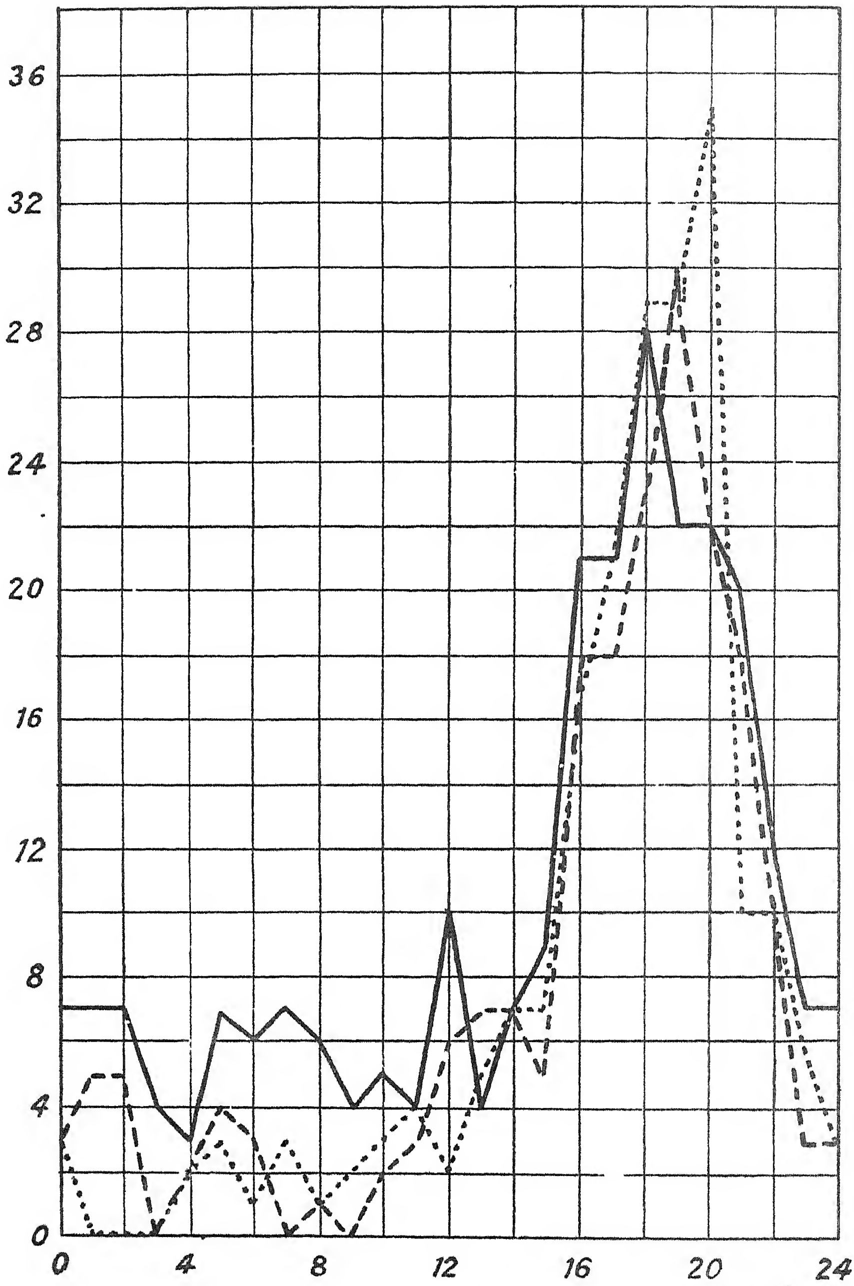

—— 1937-38 - - - 1940-41 ...... 1944-45.

Fig. 4. Diurnal variation of the frequency of micropulsation at Alibag.

GPI P POONA 1947

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Computation of winds in the atmosphere in low latitudes
Part 1—Stationary Pressure Systems

BY
S. K. PRAMANIK.

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COMPUTATION OF WINDS IN THE ATMOSPHERE IN LOW LATITUDES.

Part I. Stationary Pressure Systems.

BY

S. K. PRAMANIK.

(*Received on 25th January 1946*).

Abstract.—Radiosonde ascents are being taken from a number of stations in India and the geostrophic wind can be obtained from the isobaric charts. The geostrophic wind, however, differs quite appreciably in Indian latitudes from the gradient wind, which gives a staisfactory approximation to the true wind. The percentage corrections required to be applied to the geostrophic wind to obtain the gradient wind for different velocities of geostrophic wind and radii of curvature of trajectories for cyclonic and anti-cyclonic motions at latitudes 10°, 20° and 30° have been obtained in this note. It is difficult to obtain the curvatures of trajectories, but in stationary pressure systems they are equal to the curvatures of isobars, which are readily obtainable. The tables in this note can therefore be applied to obtain the corrections from the curvatures of isobars in stationary pressure systems.

Often during the monsoon season over most of India, and occasionally during the other seasons over parts of the country affected by storms and disturbances, upper wind data from pilot balloon ascents are not available, particularly at higher levels due to clouds and rain. So far, only a rough idea of the winds aloft has been available in these circumstances from the surface isobaric charts and observations of cloud movements. Radio-Sonde and aeroplane ascents, which are now being taken regularly from a network of stations in and around India giving pressures and temperatures at various heights over the stations, provide data from which upper winds may be obtained. One can calculate the geostrophic winds from the isobaric pressure charts at different levels, but these do not give a satisfactory approximation to the gradient wind, as the cyclostrophic component, which generally becomes important even at higher latitude, becomes very much more so in Indian latitudes. It is, therefore, necessary to obtain an idea of the correction that has to be applied to the geostrophic wind to obtain the gradient wind.

2 In a recent paper* Petterssen has obtained the percentage correction as follows :—

If M is the ratio of the geostrophic to the gradient wind, V_o the geostrophic wind, and G the gradient wind

$$V_o = MG \qquad \ldots \qquad (1)$$

$$G = V_o + \frac{G^2}{r\lambda} \qquad \ldots \qquad (2)$$

where r is the radius of curvature of trajectory being positive in anticyclonic and negative in cyclonic motion and $\lambda = 2w \operatorname{Sin} \varphi$

From (1) and (2) we get

$$M(M-1) = -\frac{V_o}{\lambda r}$$

$$\text{or } M = \tfrac{1}{2} + \sqrt{\tfrac{1}{4} - \frac{V_o}{\lambda r}} \qquad \ldots \qquad (3)$$

M can be taken as a measure of fit, so that M=1·2 indicates plus 20% error and M= ·7 minus 30 % in the approximation.

* Synoptic Division Technical Memorandum No. 78, Meteorological Office, London.

Petterssen calculated the errors for different velocities and radii of curvature for latitudes, 60°, 45° and 30°. He concluded that (even in these latitudes) although the geostrophic wind is a reasonably good approximation to the true wind immediately above sea level (when the winds are comparatively light), it is in general an unsatisfactory approximation in the free atmosphere (where the winds are normally strong).

3. The percentage corrections for latitudes 10°, 20° and 30° for different velocities and curvatures have been calculated from equation (3) and are given in *Tables I* and *II*. The corrections for latitude 30° are for different velocities and curvatures from those given by Petterssen.

TABLE I.

Percentage corrections to be applied to the geostrophic wind to obtain the gradient wind

CYCLONIC MOTION (corrections to be subtracted).

Velocity V_o (knots).	Latitude.	Radius of curvature (kms.) 100	150	200	500	1000	2000	4000	8000
10	10°	A	A	62	31	17	9	5	2
	20°	63	47	37	17	9	5	2	1
	30°	47	33	27	12	7	3	2	1
20	10°	A	A	A	53	31	17	9	5
	20°	A	A	63	31	17	9	5	3
	30°	A	59	47	23	12	7	3	2
30	10°	A	A	A	66	42	24	13	7
	20°	A	A	83	43	25	14	7	4
	30°	A	A	64	32	18	10	5	2
40	10°	A	A	A	A	53	31	17	9
	20°	A	A	A	58	31	17	9	5
	30°	A	A	78	39	23	12	7	3
50	10°	A	A	A	A	62	37	21	11
	20°	A	A	A	63	37	21	9	4
	30°	A	A	91	47	27	15	8	4
60	10°	A	A	A	A	71	42	24	15
	20°	A	A	A	71	43	25	13	7
	30°	A	A	A	53	33	17	10	5
70	10°	A	A	A	A	78	48	28	15
	20°	A	A	A	A	48	28	16	8
	30°	A	A	A	56	36	20	11	6

A :—Percentage corrections more than in the first column in which figures have been given, (*e.g.* the percentage correction for Vel. 10 knots, latitude 10°, curvature 150 km is more than 62) have not been calculated as they are very large.

Table II.

Percentage corrections to be applied to the geostrophic wind to obtain the gradient wind.

Anticyclonic motion (Corrections to be added).

Velocity V_0 knots.	Latitude.	Radius of curvature (kms.)					
		200	500	1000	2000	4000	8000
10	10°	B	B	23	11	5	3
	20°	B	27	12	6	3	1
	30°	B	17	8	4	2	1
20	10°	B	B	B	23	11	5
	20°	B	B	27	12	6	3
	30°	B	B	17	8	4	2
30	10°	B	B	B	B	19	8
	20°	B	B	B	19	8	4
	30°	B	B	30	12	5	3
40	10°	B	B	B	B	23	11
	20°	B	B	B	27	12	6
	30°	B	B	B	17	8	4
50	10°	B	B	B	B	B	15
	20°	B	B	B	B	15	7
	30°	B	B	B	23	10	5
60	10°	B	B	B	B	B	18
	20°	B	B	B	B	19	8
	30°	B	B	B	29	12	5
70	10°	B	B	B	B	B	23
	20°	B	B	B	B	23	10
	30°	B	B	B	42	14	7

B :—Anticyclonic motion not possible.

4. The percentage correction increases with increasing curvature and with the velocity of the geostrophic wind and decreases with increasing latitude.

The percentage correction for anticyclonic motion is more than that for cyclonic motion for the same velocity of geostrophic wind and curvature.

From *Table* I, it will be seen that for cyclonic motion the correction is more than 20% for a velocity of 10 knots at 10° for curvatures of a little more than 1000 km, and for a velocity of 20 knots at 20° and 30° for curvatures of a little over 500 kms. For a velocity of 30 knots, which is fairly frequent during strong monsoon, the error is about 42% at 10°, 25% at 20° and 18% at 30° even for a curvature of 1000 km. During depressions and storms when the curvatures at places may be of the order of 200 to 500 km and velocities 30 to 50 knots or more, the error is very much more considerable.

Anticyclonic motion is, however, not possible when the correction is more than 50% and as such the corrections in all cases are not greater than 50%.

5. Although the geostrophic wind does not give a good approximation to the true wind, a fair estimate of the true wind can be obtained by applying the necessary correction corresponding to the curvature of the trajectory to the geostrophic

wind. It is, however, difficult to estimate the curvature of trajectories but the curvatures of isobars can be obtained fairly readily. The question of estimating corrections from the curvatures of isobars to be applied to geostrophic wind to obtain the gradient wind is under consideration and will be dealt with in a further note.

DGO. 19. X. 128.
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COMPUTATION OF WINDS IN THE ATMOSPHERE IN LOW LATITUDES

PART II.—MOVING PRESSURE SYSTEMS

BY

S. K. PRAMANIK AND S. MAZUMDAR

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551. 553. 57

COMPUTATION OF WINDS IN THE ATMOSPHERE IN LOW LATITUDES.

Part II.—Moving Pressure Systems.

BY

S. K. PRAMANIK AND S. MAZUMDAR.

(*Received on 25th January 1946.*)

Abstract.—In the previous Sc. note, the corrections to be applied to geostrophic wind to obtain the gradient wind from curvature of isobars in stationary pressure systems in Indian latitudes have been given. In this note, percentage corrections have been obtained for cyclonic and anticyclonic pressure systems, moving with different velocities, from curvatures of isobars for different values of geostrophic wind and inclinations of the isobars to the direction of movement of systems at latitudes 10°, 20 and 30 .

In the previous note (Sc. note 127) one of the authors[1] calculated the percentage corrections to be applied to the geostrophic wind to obtain the gradient wind, which is generally a close approximation to the true wind. In that note, in determining the corrections, the curvatures of the trajectories have been taken into account, and as the curvatures of trajectories and the curvatures of isobars are equal in stationary pressure systems, the curvatures of isobars can be used in these cases for determining the corrections from the tables. In the case of moving

[1] S. K. Pramanik: Computation of winds in the atmosphere in low latitudes. I.—Stationary pressure systems.

pressure systems, the curvatures of isobars are different from those of trajectories and the following method, due to Petterssen[1], can be used to determine from the curvature of isobars the corrections to be applied to the geostrophic wind to obtain the gradient wind.

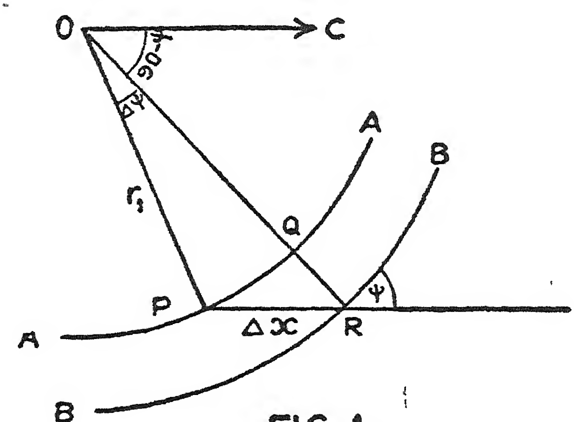

FIG. 1.

Let O in *Fig. 1* be the centre of the curvature of two neighbouring isobars AA and BB.

Let C=the velocity with which the pressure system travels,

V_o=Geostrophic wind,

V=true wind,

G=Gradient wind,

$\lambda=2\,\omega\sin\,\varphi$, where φ is the latitude and ω is the angular velocity of the rotation of the earth,

ψ=the angle between the isobar and the direction of movement of the pressure system,

$OP=r_1$= radius of curvature of isobar,

and r=radius of curvature of trajectory.

Then

$$PQ=r_1\Delta\psi$$

$$PR=\Delta\chi=\frac{PQ}{\text{Cos}\psi}$$

It follows that $\frac{\Delta\psi}{\Delta\chi}=\frac{1}{r_1}\text{Cos}\psi$

As the pressure system moves with velocity C

$$\Delta\chi=C\Delta t$$

and the angle ψ would decrease by the amount $\frac{C}{r_1}\text{Cos}\psi\;\Delta t$

Hence, when $\Delta\chi$ approximates zero,

$$\frac{d\psi}{dt}=-\frac{C}{r_1}\text{ Cos }\psi \qquad (1)$$

[1] S. Petterssen: Computation of winds in the Free Atmosphere Synoptic Division Technical Memorandum, No. 78, London.

$$\text{Again } \frac{d\psi}{dt} = \frac{\partial\psi}{\partial t} + V\frac{\partial\psi}{\partial s} = \frac{V}{r}$$

Or, since the gradient wind approximates to the true wind,

$$\frac{d\psi}{dt} = \frac{\partial\psi}{\partial t} + G\frac{\partial\psi}{\partial s} = \frac{G}{r} \tag{2}$$

Now, since the streamline of the gradient wind is the isobar,

$$\frac{\partial\psi}{\partial s} = \frac{1}{r_1} \tag{3}$$

which with (1) and (2) gives

$$\frac{1}{r} = \frac{1}{r_1}\left(1 - \frac{C}{G}\operatorname{Cos}\psi\right) \tag{4}$$

The gradient wind equation gives

$$G = V_o + \frac{G^2}{r\lambda}$$

Or

$$\frac{V_o}{G} = 1 - \frac{G}{r\lambda}$$

Or, putting $V_o = MG$, we get

$$M\left(M - 1\right) = -\frac{V_o}{\lambda r} \tag{5}$$

From (4) and (5) we get

$$M\left(1 - M + \frac{C}{r_1\lambda}\operatorname{Cos}\psi\right) = \frac{V_o}{r_1\lambda} \tag{6}$$

Or

$$M = \tfrac{1}{2}\left(1 + \frac{C}{r_1\lambda}\operatorname{Cos}\psi\right) + \sqrt{\tfrac{1}{4} + \tfrac{1}{2}\frac{C}{r_1\lambda}\operatorname{Cos}\psi + \tfrac{1}{4}\frac{C^2}{r_1^2}\frac{\operatorname{Cos}^2\psi}{\lambda^2} - \frac{V_o}{r_1\lambda}} \tag{7}$$

For cyclonic circulation we get

$$M = \tfrac{1}{2}\left(1 - \frac{C}{r_1\lambda}\operatorname{Cos}\psi\right) + \sqrt{\tfrac{1}{4} - \tfrac{1}{2}\frac{C}{r_1\lambda}\operatorname{Cos}\psi + \tfrac{1}{4}\frac{C^2}{r_1^2}\frac{\operatorname{Cos}^2\psi}{\lambda^2} + \frac{V_o}{r_1\lambda}} \tag{8}$$

Now M can be regarded as a measure of fit such that $M = 1{\cdot}3$ indicates *plus* 30% error, and $M = {\cdot}8$ indicates *minus* twenty per cent. error in the geostrophic approximation. The percentage correction would thus be 100 (1—M).

A. Cyclonic moving pressure systems.

The values of M were calculated from equation (8) for values of $c = 5, 10, 15$ knots, $V_o = 10, 20, 30, 40, 50, 60, 70$ knots, $\varphi = 10°, 20°, 30°$, $\psi = 0°, 30°, 60°, 120°, 150°, 180°$, and $r_1 = 200, 500, 1{,}000, 2{,}000, 4{,}000, 8{,}000$, kms. and are given in the tables below.

Corrections to be applied to the geostrophic wind to obtain the gradient wind for various values of V_o, φ, ψ, c and r_1.

Table 1. $\varphi=10^\circ$, $c=5$, $\psi=0^\circ$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	1·23	—	—	—	—	—	—
500	1·15	1·38	1·56	—	—	—	—
1,000	1·03	1·22	1·34	1·45	1·55	—	—
2,000	1·05	1·13	1·20	1·27	1·33	1·39	1·44
4,000	1·02	1·06	1·11	1·15	1·18	1·22	1·25
8,000	1·02	1·04	1·07	1·08	1·11	1·12	1·15

Table 2. $\varphi=10^\circ$, $c=5$, $\psi=30^\circ$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	1·33	—	—	—	—	—	—
500	1·17	1·40	1·58	—	—	—	—
1,000	1·09	1·23	1·35	1·46	1·55	—	—
2,000	1·05	1·13	1·20	1·27	1·33	1·39	1·44
4,000	1·02	1·06	1·11	1·15	1·18	1·22	1·25
8,000	1·02	1·04	1·07	1·08	1·11	1·12	1·15

Table 3. $\varphi=10^\circ$, $c=5$, $\psi=60^\circ$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	1·45	—	—	—	—	—	—
500	1·22	1·45	—	—	—	—	—
1,000	1·13	1·27	1·39	1·49	1·58	—	—
2,000	1·06	1·15	1·22	1·28	1·34	1·40	1·45
4,000	1·04	1·08	1·12	1·16	1·20	1·23	1·27
8,000	1·03	1·05	1·07	1·09	1·12	1·13	1·16

Table 4. $\varphi=10^\circ$, $c=5$, $\psi=120^\circ$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	—	—	—	—	—	—	—
500	1·39	—	—	—	—	—	—
1,000	1·22	1·35	1·47	—	—	—	—
2,000	1·13	1·19	1·26	1·33	1·39	1·44	1·49
4,000	1·06	1·10	1·14	1·18	1·21	1·25	1·28
8,000	1·03	1·05	1·07	1·09	1·12	1·13	1·16

Table 5. $\varphi=10^\circ$, $c=5$, $\psi=150^\circ$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	—	—	—	—	—	—	—
500	1·45	—	—	—	—	—	—
1,000	1·25	1·38	1·49	—	—	—	—
2,000	1·15	1·22	1·29	1·35	1·41	1·47	1·52
4,000	1·09	1·13	1·17	1·20	1·24	1·27	1·31
8,000	1·05	1·07	1·09	1·11	1·13	1·15	1·16

Table 6. $\varphi=10^\circ$, $c=5$, $\psi=180^\circ$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	—	—	—	—	—	—	—
500	1·47	—	—	—	—	—	—
1,000	1·26	1·39	1·50	—	—	—	—
2,000	1·15	1·22	1·29	1·35	1·41	1·47	1·52
4,000	1·09	1·13	1·17	1·20	1·24	1·27	1·31
8,000	1·05	1·07	1·09	1·11	1·13	1·15	1·16

Table 7. $\varphi=10^\circ$, $c=10$, $\psi=0^\circ$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	1·00	1·41	—	—	—	—	—
500	1·00	1·24	1·43	1·60	—	—	—
1,000	1·00	1·15	1·27	1·38	1·43	1·57	—
2,000	1·00	1·08	1·16	1·22	1·29	1·34	1·40
4,000	1·00	1·04	1·09	1·13	1·16	1·20	1·23
8,000	1·00	1·02	1·05	1·06	1·09	1·11	1·13

Table 8. $\varphi=10^\circ$, $c=10$, $\psi=30^\circ$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	1·07	1·49	—	—	—	—	—
500	1·04	1·28	1·47	—	—	—	—
1,000	1·02	1·16	1·29	1·39	1·49	1·58	—
2,000	1·00	1·08	1·16	1·22	1·29	1·34	1·40
4,000	1·00	1·04	1·09	1·13	1·16	1·20	1·23
8,000	1·00	1·02	1·05	1·06	1·09	1·11	1·13

Table 9. $\varphi=10^\circ$, $c=10$, $\psi=60^\circ$

Same as Table 1 where
$\varphi=10^\circ$, $c=5$, $\psi=0^\circ$.

Table 10. $\varphi=10^\circ$, $c=10$, $\psi=120^\circ$

Same as Table 6 where
$\varphi=10^\circ$, $c=5$, $\psi=180^\circ$.

Table 11. $\varphi=10^\circ$, $c=10$, $\psi=150^\circ$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	—	—	—	—	—	—	—
500	—	—	—	—	—	—	—
1,000	1·36	1·46	1·56	—	—	—	—
2,000	1·18	1·26	1·32	1·39	1·44	1·50	1·55
4,000	1·10	1·15	1·19	1·22	1·26	1·29	1·32
8,000	1·06	1·08	1·10	1·12	1·14	1·16	1·18

Table 12. $\varphi=10^\circ$, $c=10$, $\psi=180^\circ$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	—	—	—	—	—	—	—
500	—	—	—	—	—	—	—
1,000	1·35	1·47	1·58	—	—	—	—
2,000	1·18	1·26	1·32	1·39	1·44	1·50	1·55
4,000	1·10	1·15	1·19	1·22	1·26	1·29	1·32
8,000	1·06	1·08	1·10	1·12	1·14	1·16	1·18

Table 13. $\varphi=10^\circ$, $c=15$, $\psi=0^\circ$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	0·78	1·36	1·50	—	—	—	—
500	0·86	1·12	1·34	1·47	—	—	—
1,000	0·92	1·07	1·20	1·31	1·41	—	—
2,000	0·94	1·05	1·11	1·18	1·24	1·30	1·36
4,000	0·97	1·02	1·06	1·10	1·14	1·17	1·21
8,000	0·99	1·01	1·04	1·05	1·07	1·10	1·12

Table 14. $\varphi=10^\circ$, $c=15$, $\psi=30^\circ$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	0·86	1·27	—	—	—	—	—
500	0·92	1·17	1·36	1·53	—	—	—
1,000	0·95	1·10	1·23	1·34	1·44	1·53	—
2,000	0·97	1·06	1·14	1·21	1·27	1·33	1·38
4,000	0·97	1·02	1·06	1·10	1·14	1·17	1·21
8,000	0·99	1·01	1·04	1·05	1·07	1·10	1·12

Table 15. $\varphi=10°$, $c=15$, $\psi=90°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	1·18	1·58	—	—	—	—	—
500	1·07	1·31	1·50	—	—	—	—
1,000	1·05	1·19	1·31	1·42	1·52	—	—
2,000	1·02	1·10	1·17	1·24	1·30	1·36	1·41
4,000	1·01	1·05	1·10	1·14	1·17	1·21	1·24
8,000	1·01	1·03	1·06	1·07	1·10	1·11	1·14

Table 16. $\varphi=10°$, $c=15$, $\psi=120°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	—	—	—	—	—	—	
500	1·56	—	—	—	—	—	—
1,000	1·31	1·44	1·55	—	—	—	—
2,000	1·16	1·24	1·31	1·37	1·43	1·48	1·53
4,000	1·09	1·13	1·17	1·20	1·24	1·27	1·31
8,000	1·05	1·07	1·09	1·11	1·11	1·15	1·17

Table 17. $\varphi=10°$, $c=15$, $\psi=150°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	—	—	—	—	—	—	—
500	—	—	—	—	—	—	—
1,000	1·40	1·52	—	—	—	—	—
2,000	1·23	1·30	1·36	1·42	1·48	1·53	—
4,000	1·12	1·16	1·20	1·24	1·27	1·31	1·34
8,000	1·07	1·09	1·11	1·13	1·15	1·17	1·19

Table 18. $\varphi=10°$, $c=15$, $\psi=180°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	—	—	—	—	—	—	
500	—	—	—	—	—	—	—
1,000	1·44	—	—	—	—	—	—
2,000	1·24	1·31	1·38	1·44	1·50	—	—
4,000	1·12	1·16	1·20	1·24	1·27	1·31	1·34
8,000	1·07	1·09	1·11	1·13	1·15	1·17	1·19

Table 19. $\varphi=20°$, $c=5$, $\psi=0°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	1·18	1·48	—	—	—	—	—
500	1·09	1·24	1·36	1·47	—	—	—
1,000	1·05	1·14	1·22	1·28	1·34	1·40	1·45
2,000	1·03	1·07	1·12	1·16	1·19	1·23	1·26
4,000	1·02	1·05	1·07	1·09	1·11	1·13	1·15
8,000	1·01	1·03	1·04	1·05	1·06	1·07	1·08

Table 20. $\varphi=20°$, $c=5$, $\psi=30°$

r_1 (kms.)	V_0 (knots). 10	20	30	40	50	60	70
200	1·21	1·52	—	—	—	—	—
500	1·10	1·25	1·37	1·48	—	—	—
1,000	1·06	1·14	1·21	1·28	1·34	1·40	1·45
2,000	1·03	1·08	1·12	1·16	1·19	1·23	1·26
4,000	1·02	1·04	1·07	1·09	1·11	1·13	1·15
8,000	1·01	1·02	1·03	1·05	1·06	1·07	1·08

TABLE 21. $\varphi=20°$, $c=5$, $\psi=60°$

r_1 (kms.)	V_0 (knots)						
	10	20	30	40	50	60	70
200	1·28	1·54	—	—	—	—	—
500	1·13	1·27	1·39	1·[illegible]9	—	—	—
1,000	1·07	1·15	1·23	1·30	1·36	1·42	1·47
2,000	1·04	1·03	1·12	1·17	1·20	1·23	1·27
4,000	1·02	1·05	1·07	1·09	1·11	1·13	1·16
8,000	1·01	1·02	1·04	1·05	1·06	1·07	1·08

TABLE 22. $\varphi=20°$, $c=5$, $\psi=120°$

r_1 (kms.)	V_0 (knots)						
	10	20	30	40	50	60	70
200	1·47	—	—	—	—	—	—
500	1·22	1·36	1·48	—	—	—	—
1,000	1·12	1·19	1·26	1·33	1·39	1·45	1·50
2,000	1·07	1·11	1·15	1·19	1·22	1·26	1·30
4,000	1·03	1·06	1·08	1·10	1·12	1·14	1·16
8,000	1·02	1·03	1·04	1·05	1·07	1·07	1·08

TABLE 23. $\varphi=20°$, $c=5$, $\psi=150°$

r_1 (kms.)	V_0 (knots)						
	10	20	30	40	50	60	70
200	—	—	—	—	—	—	—
500	1·25	1·38	1·50	—	—	—	—
1,000	1·[illegible]4	1·21	1·28	1·35	1·41	1·46	—
2,000	1·07	1·11	1·16	1·19	1·23	1·26	1·30
4,000	1·04	1·06	1·09	1·11	1·13	1·15	1·17
8,000	1·02	1·03	1·04	1·05	1·06	1·07	1·08

TABLE 24. $\varphi=20°$, $c=5$, $\psi=180°$

r_1 (kms.)	V_0 (knots)						
	10	20	30	40	50	60	70
200	1·58	—	—	—	—	—	—
500	1·26	1·40	1·51	—	—	—	—
1,000	1·15	1·23	1·30	1·36	1·42	1·47	—
2,000	1·08	1·13	1·17	1·21	1·24	1·28	1·31
4,000	1·04	1·06	1·09	1·11	1·13	1·15	1·17
8,000	1·02	1·03	1·04	1·06	1·07	1·08	1·09

TABLE 25. $\varphi=20°$, $c=10$, $\psi=0°$

r_1 (kms.)	V_0 (knots)						
	10	20	30	40	50	60	70
200	1·00	1·29	1·51	—	—	—	—
500	1·00	1·16	1·28	1·39	1·49	—	—
1,000	1·00	1·09	1·16	1·23	1·30	1·36	1·41
2,000	1·01	1·05	1·10	1·14	1·17	1·21	1·25
4,000	1·00	1·03	1·05	1·07	1·09	1·12	1·14
8,000	1·01	1·02	1·03	1·05	1·06	1·07	1·0[illegible]

TABLE 26. $\varphi=20°$, $c=10$, $\psi=30°$

r_1 (kms.)	V_0 (knots)						
	10	20	30	40	50	60	70
200	1·05	1·33	1·55	—	—	—	—
500	1·02	1·17	1·30	1·40	1·51	—	—
1,000	1·02	1·10	1·18	1·25	1·31	1·37	1·42
2,000	1·01	1·05	1·10	1·14	1·18	1·21	1·25
4,000	1·00	1·03	1·06	1·08	1·10	1·12	1·14
8,000	1·01	1·02	1·03	1·05	1·06	1·07	1·07

TABLE 27. $\varphi=20^\circ$, $c=10$, $\psi=60^\circ$
Same as Table 19 where
$\varphi=20^\circ$, $c=5$, $\psi=0^\circ$.

TABLE 28. $\varphi=20^\circ$, $c=10$, $\psi=120^\circ$
Same as Table 24 where
$\varphi=20^\circ$, $c=5$, $\psi=180^\circ$.

TABLE 29. $\varphi=20^\circ$, $c=10$, $\psi=150^\circ$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	—	—	—	—	—	—	—
500	1·33	1·47	—	—	—	—	—
1,000	1·18	1·26	1·33	1·39	1·45	1·50	—
2,000	1·10	1·15	1·19	1·22	1 26	1 29	1 33
4,000	1 05	1 07	1·09	1·11	1·13	1·15	1·17
8,000	1·02	1·03	1·05	1 06	1·07	1·07	1·09

TABLE 30. $\varphi=20^\circ$, $c=10$, $\psi=180^\circ$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	—	—	—	—	—	—	—
500	1·35	1·48	—	—	—	—	—
1,000	1·19	1·26	1·33	1·40	1·46	1·51	—
2,000	1·10	1·15	1·19	1·22	1·26	1·30	1 33
4,000	1 06	1 09	1·10	1·13	1·14	1·17	1 18
8,000	1 03	1·04	1·06	1 07	1·08	1 09	1·10

TABLE 31. $\varphi=20^\circ$ $c=15$, $\psi=0^\circ$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	0·84	1·13	1·33	—	—	—	—
500	0 92	1·08	1·21	1·32	1·42	—	—
1,000	0·96	1·05	1·13	1·20	1·26	1·32	1·38
2,000	0 98	1 03	1 07	1·11	1·14	1·18	1·22
4,000	0·99	1·01	1 04	1·05	1·08	1·10	1·12
8,000	0·99	1 01	1·02	1·03	1·04	1·06	1·06

TABLE 32. $\varphi=20^\circ$, $c=15$, $\psi=30^\circ$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	0·91	1·20	1·46	—	—	—	—
500	0 95	1·11	1·25	1·35	1·45	—	—
1,000	0·97	1·05	1·13	1·20	1·27	1·32	1·38
2,000	0·99	1·04	1·08	1·12	1·16	1·20	1·23
4,000	1·00	1·02	1 05	1·07	1·09	1·11	1.18
8,000	0·99	1·01	1·02	1·03	1·05	1·06	1·06

TABLE 33. $\varphi=20^\circ$, $c=15$, $\psi=60$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	1·08	1·26	—	—	—	—	—
500	1·04	1·19	1·31	1 42	—	—	—
1,000	1·03	1·11	1·18	1·25	1·31	1·37	1·43
2,000	1·02	1·06	1·10	1·14	1·18	1.21	1·25
4,000	1·01	1·04	1·06	1·08	1·10	1·12	1·15
8,000	1·01	1·02	1·03	1·05	1·06	1 07	1·08

TABLE 34. $\varphi=20^\circ$, $c=15$, $\psi=120^\circ$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	—	—	—	—	—	—	—
500	1·31	1·45	—	—	—	—	—
1,000	1·16	1·25	1·31	1·38	1·44	1·49	—
2,000	1·09	1·14	1·18	1·21	1·25	1·28	1 32
4,000	1·04	1·07	1·09	1·12	1·13	1·16	1·18
8,000	1·03	1·04	1·05	1·07	1·08	1·09	1·10

Table 35. $\varphi=20°$, $c=15$, $\psi=150°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	—	—	—	—	—	—	—
500	1·41	—	—	—	—	—	—
1,000	1·23	1·30	1·36	1·42	1·48	—	—
2,000	1·11	1·15	1·19	1·23	1·26	1·30	1·33
4,000	1·06	1·09	1·11	1·13	1·14	1·17	1·18
8,000	1·03	1·04	1·06	1·07	1·08	1·09	1·10

Table 36 $\varphi=20°$, $c=15$, $\psi=180°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	—	—	—	—	—	—	—
500	1·45	—	—	—	—	—	—
1,000	1·24	1·31	1·38	1·45	1·50	—	—
2,000	1·12	1·16	1·21	1·25	1·28	1·31	1·35
4,000	1·07	1·09	1·11	1·13	1·15	1·17	1·19
8,000	1·03	1·05	1·06	1·07	1·08	1·09	1·10

Table 37. $\varphi=30°$, $c=5$, $\psi=0°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	1·14	1·36	1·53	—	—	—	—
500	1·06	1·17	1·26	1·35	1·42	1·50	—
1,000	1·03	1·09	1·15	1·20	1·25	1·29	1·33
2,000	1·02	1·05	1·08	1·11	1·14	1·18	1·19
4,000	1·01	1·02	1·04	1·06	1·07	1·09	1·10
8,000	1·00	1·01	1·02	1·03	1·04	1·05	1·06

Table 38. $\varphi=30°$, $c=5$, $\psi=30°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	1·17	1·38	1·55	—	—	—	—
500	1·07	1·18	1·23	1·36	1·44	1·50	1·57
1,000	1·04	1·10	1·16	1·21	1·26	1·31	1·35
2,000	1·03	1·06	1·09	1·12	1·15	1·18	1·20
4,000	1·02	1·03	1·05	1·07	1·08	1·09	1·11
8,000	1·01	1·02	1·03	1·03	1·04	1·05	1·06

Table 39. $\varphi=30°$, $c=5$, $\psi=60°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	1·27	1·46	—	—	—	—	—
500	1·09	1·20	1·29	1·37	1·45	1·52	—
1,000	1·05	1·11	1·16	1·21	1·26	1·31	1·35
2,000	1·03	1·06	1·09	1·12	1·15	1·18	1·20
4,000	1·02	1·03	1·05	1·07	1·08	1·09	1·11
8,000	1·01	1·02	1·03	1·03	1·04	1·05	1·06

Table 40. $\varphi=30$, $c=5$, $\psi=120°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	1·36	1·56	—	—	—	—	—
500	1·16	1·26	1·35	1·45	1·53	—	—
1,000	1·09	1·14	1·20	1·25	1·30	1·34	1·39
2,000	1·04	1·07	1·11	1·13	1·16	1·18	1·21
4,000	1·02	1·03	1·05	1·07	1·08	1·09	1·11
8,000	1·01	1·02	1·03	1·03	1·04	1·05	1·06

Table 41. $\varphi=30°$, $c=5$, $\psi=150°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	1·40	—	—	—	—	—	—
500	1·18	1·23	1·37	1·45	—	—	—
1,000	1·09	1·16	1·21	1·26	1·31	1·35	1·40
2,000	1·05	1·08	1·12	1·14	1·17	1·19	1·22
4,000	1·03	1·05	1·07	1·08	1·10	1·11	1·13
8,000	1·01	1·02	1·03	1·04	1·05	1·06	1·07

Table 42. $\varphi=30°$, $c=5$, $\psi=180°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	1·44	—	—	—	—	—	—
500	1·20	1·29	1·39	1·47	1·54	—	—
1,000	1·10	1·16	1·23	1·26	1·31	1·35	1·40
2,000	1·05	1·08	1·11	1·14	1·17	1·20	1·22
4,000	1·03	1·05	1·06	1·08	1·10	1·11	1·13
8,000	1·01	1·02	1·03	1·04	1·05	1·05	1·06

Table 43. $\varphi=30°$, $c=10$, $\psi=0°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	1·06	1·27	1·44	1·59	—	—	—
500	1·01	1.12	1·21	1·30	1·38	1·45	1·51
1,000	1·00	1·06	1·12	1·17	1·22	1·26	1·31
2,000	1·00	1·03	1·06	1·09	1·12	1·14	1·17
4,000	1·00	1·02	1·03	1·05	1·06	1·08	1·09
8,000	1·01	1·02	1·03	1·04	1·04	1·05	1·06

Table 44. $\varphi=30°$, $c=10$, $\psi=30°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	1·08	1·29	1·46	—	—	—	—
500	1·02	1·13	1·22	1·31	1·39	1·46	1·52
1,000	1·01	1·07	1·13	1·17	1·22	1·26	1·31
2,000	1·00	1·03	1·06	1·09	1·12	1·14	1·17
4,000	1·00	1·02	1·03	1·05	1·06	1·08	1·09
8,000	1·01	1·02	1·03	1·04	1·04	1·05	1·06

Table 45. $\varphi = 30°$, $c = 10$, $\psi = 60°$

Same as Table 37 where

$\varphi = 30°$, $c = 5$, $\psi = 0°$.

Table 46. $\varphi = 30°$, $c = 10$, $\psi = 120°$

Same as Table 42 where

$\varphi = 30°$, $c = 5$, $\psi = 180°$.

Table 47. $\varphi = 30°$, $c = 10$, $\psi = 150°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	1·57	—	—	—	—	—	—
500	1·24	1·33	1·42	1·50	1·57	—	—
1,000	1·12	1·18	1·23	1·28	1·34	1·38	1·42
2,000	1·03	1·10	1·14	1·16	1·18	1·21	1·23
4,000	1·04	1·06	1·08	1·09	1·10	1·12	1·13
8,000	1·01	1·02	1·03	1·04	1·04	1·05	1·06

Table 48. $\varphi = 30°$, $c = 10$, $\psi = 180°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	—	—	—	—	—	—	—
500	1·26	1·36	1·44	1·52	1·59	—	—
1,000	1·14	1·20	1·25	1·30	1·34	1·38	1·42
2,000	1·03	1·10	1·14	1·16	1·18	1·21	1·23
4,000	1·04	1·06	1·08	1·09	1·10	1·12	1·13
8,000	1·01	1·02	1·03	1·04	1·04	1·05	1·06

TABLE 49. $\varphi = 30°$, $c = 15$, $\psi = 0°$

r_1 (kms.)	V_c (knots)						
	10	20	30	40	50	60	70
200	0·83	1·11	1·29	1·44	1·58	—	—
500	0·95	1·06	1·16	1·25	1·33	1·40	1·47
1,000	0·97	1·03	1·09	1·14	1·19	1·24	1·28
2,000	0·99	1·02	1·05	1·08	1·11	1·14	1·16
4,000	1·00	1·02	1·03	1·05	1·06	1·08	1·09
8,000	1·01	1·02	1·03	1·04	1·05	1·06	1·06

TABLE 50. $\varphi = 30°$, $c = 15$, $\psi = 30°$

r_1 (kms.)	V_c (knots)						
	10	20	30	40	50	60	70
200	0·93	1·16	1·34	1·49	—	—	—
500	0·97	1·08	1·18	1·26	1·34	1·42	1·48
1,000	0·98	1·04	1·10	1·15	1·20	1·25	1·29
2,000	0·99	1·02	1·05	1·08	1·11	1·14	1·16
4,000	1·00	1·02	1·03	1·05	1·06	1·08	1·09
8,000	1·01	1·02	1·0	1·04	1·05	1·05	1·06

TABLE 51. $\varphi = 30°$, $c = 15$, $\psi = 60°$

r_1 (kms.)	V_c (knots)						
	10	20	30	40	50	60	70
200	1·07	1·29	1·46	—	—	—	—
500	1·03	1·14	1·24	1·32	1·40	1·47	1·54
1,000	1·01	1·07	1·13	1·18	1·22	1·27	1·31
2,000	1·01	1·03	1·06	1·09	1·12	1·14	1·17
4,000	1·01	1·03	1·04	1·05	1·06	1·08	1·09
8,000	1·01	1·02	1·03	1·04	1·05	1·05	1·06

TABLE 52. $\varphi = 30°$, $c = 15$, $\psi = 120°$

r_1 (kms.)	V_c (knots)						
	10	20	30	40	50	60	70
200	1·50	—	—	—	—	—	—
500	1·22	1·32	1·41	1·49	1·56	—	—
1,000	1·12	1·18	1·23	1·28	1·32	1·37	1·41
2,000	1·08	1·10	1·14	1·16	1·19	1·21	1·24
4,000	1·04	1·06	1·08	1·08	1·10	1·12	1·13
8,000	1·01	1·02	1·03	1·04	1·05	1·05	1·06

TABLE 53. $\varphi = 30°$, $c = 15$, $\psi = 150°$

r_1 (kms.)	V_c (knots)						
	10	20	30	40	50	60	70
200	—	—	—	—	—	—	—
500	1·29	1·38	1·45	1·54	—	—	—
1,000	1·16	1·21	1·26	1·31	1·36	1·40	1·44
2,000	1·10	1·12	1·15	1·18	1·21	1·23	1·26
4,000	1·04	1·06	1·07	1·08	1·10	1·12	1·13
8,000	1·01	1·02	1·03	1·04	1·05	1·05	1·06

TABLE 54. $\varphi = 30°$, $c = 15$, $\psi = 180°$

r_1 (kms.)	V_c (knots)						
	10	20	30	40	50	60	70
200	—	—	—	—	—	—	—
500	1·32	1·41	1·49	—	—	—	—
1,000	1·16	1·21	1·26	1·31	1·36	1·40	1·44
2,000	1·10	1·12	1·15	1·18	1·21	1·23	1·26
4,000	1·04	1·06	1·07	1·08	1·10	1·12	1·13
8,000	1·01	1·02	1·03	1·04	1·05	1·05	1·06

(— indicates values of M well over 1·50, which have not been calculated.)

In column 2 (V_o=10) in tables 13, 14, 31, 32, 49 and 50 (c=15, ψ=0° and 30°, φ=10°, 20° and 30°), most of the values of M are less than 1, indicating that the trajectories in these cases are anticyclonic.

From equation (4) the circulation along the isobars and trajectories at any place are of the same kind, cyclonic or anticyclonic so long as C cos ψ is less than G. Where the value of C cos ψ is, however, greater than G, the circulation along the isobars and the trajectories are of opposite sign. In the present case the circulation along the isobars is cyclonic, so the trajectories are anticyclonic in the cases for which M is less than 1.

To obtain the gradient wind: Calculate the geostrophic wind, estimate c, measure the radius of curvature of the isobar with a transparent scale and measure ψ from the synoptic charts, then obtain the values of M from the appropriate table and correct the geostrophic wind accordingly to obtain the gradient wind.

Thus, if the geostrophic wind is 30 knots, c=5 knots, radius of curvature=1,000 kms., ψ=30° and the place is near latitude 20°, the value of M from table 20 is 1·21 and the gradient wind is 25 knots.

Or, if the geostrophic wind is 40 knots, c=10 knots, radius of curvature=500 kms., ψ=150°, and the place is near latitude 30°, the value of M from table 47 is 1·50 and the gradient wind is 27 knots.

B.—Anticyclonic moving pressure systems.

The values of M were calculated from equation (7) for values of c=5, 10 and 15 knots, V_o=10, 20, 30, 40, 50, 60 and 70 knots, φ=10°, 20° and 30°, ψ=0°, 30°, 60°, 120°, 150° and 180°, and r_1=200, 500, 1,000, 2,000, 4,000, 8,000 kms., and are given in the 54 tables below.

Corrections to be applied to the geostrophic wind to obtain the gradient wind for various values of V_o, φ, c, ψ and r_1.

TABLE 1. φ=10°, c=5, ψ=0°

r_1 (kms.)	V_o (knots)						
	10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	×	×	×	×	×	×	×
1,000	0·87	×	×	×	×	×	×
2,000	0·95	0·78	×	×	×	×	×
4,000	0·97	0·91	0·84	0·76	0·61	×	×
8,000	0·98	0·96	0·92	0·90	0·87	0·83	0·78

TABLE 2. φ=10°, c=5, ψ=30°

r_1 (kms.)	V_o (knots)						
	10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	×	×	×	×	×	×	×
1,000	0·85	×	×	×	×	×	×
2,000	0·94	0·80	×	×	×	×	×
4,000	0·97	0·91	0·84	0·76	0·61	×	×
8,000	0·98	0·96	0·92	0·90	0·87	0·83	0·78

TABLE 3. $\varphi=10^\circ$, $c=5$, $\psi=60^\circ$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	×	×	×	×	×	×	×
1,000	0·81	×	×	×	×	×	×
2,000	0·93	0·73	×	×	×	×	×
4,000	0·97	0·91	0·84	0·76	0·61	×	×
8,000	0·97	0·95	0·91	0·89	0·85	0·82	0·76

TABLE 4. $\varphi=10^\circ$, $c=5$, $\psi=120^\circ$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	×	×	×	×	×	×	×
1,000	0·62	×	×	×	×	×	×
2,000	0·85	0·66	×	×	×	×	×
4,000	0·94	0·87	0·80	0·70	×	×	×
8,000	0·97	0·95	0·91	0·89	0·85	0·81	0·76

TABLE 5. $\varphi=10^\circ$, $c=5$, $\psi=150^\circ$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	×	×	×	×	×	×	×
1,000		×	×	×	×	×	×
2,000	0·83	0·62	×	×	×	×	×
4,000	0·93	0·86	0·79	0·69	×	×	×
8,000	0·96	0·94	0·89	0·87	0·83	0·80	0·75

TABLE 6. $\varphi=10^\circ$, $c=5$, $\psi=180^\circ$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	×	×	×	×	×	×	×
1,000	0·45	×	×	×	×	×	×
2,000	0·83	0·62	×	×	×	×	×
4,000	0·93	0·86	0·79	0.69	×	×	×
8,000	0·96	0·94	0·89	0·87	0·83	0·80	0·75

TABLE 7. $\varphi=10^\circ$, $c=10$, $\psi=0^\circ$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	1·00	×	×	×	×	×	×
1,000	1·00	×	×	×	×	×	×
2,000	1·00	0·86	0·55	×	×	×	×
4,000	1·01	0·95	0·89	0·81	0·70	×	×
8,000	1·00	0·9[illegible]	0·95	0·92	0·[illegible]8	0·86	0·81

TABLE 8. $\varphi=10^\circ$, $c=10$, $\psi=30^\circ$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	0·93	×	×	×	×	×	×
1,000	0·98	×	×	×	×	×	×
2,000	1·00	0·86	0·55	×	×	×	×
4,000	1·01	0·95	0·89	0·81	0·70	×	×
8,000	1·00	0·98	0·95	0·92	0·88	0·86	0·81

TABLE 9. $\varphi=10^\circ$, $c=10$, $\psi=60^\circ$

Same as Table 1 where

$\varphi=10^\circ$, $c=5$, $\psi=0^\circ$

TABLE 10. $\varphi=10^\circ$, $c=10$, $\psi=120^\circ$

Same as Table 6 where

$\varphi=10^\circ$, $c=5$, $\psi=180^\circ$

TABLE 11. $\varphi=10^\circ$, $c=10$, $\psi=150^\circ$

r_1 (kms.)	V_o (knots)						
	10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	×	×	×	×	×	×	×
1,000	×	×	×	×	×	×	×
2,000	0·76	0·45	×	×	×	×	×
4,000	0·89	0·83	0·74	0·62	×	×	×
8,000	0·94	0·91	0·88	0·85	0·80	0·77	0·71

TABLE 12. $\varphi=10^\circ$, $c=10$, $\psi=180^\circ$

r_1 (kms.)	V_o (knots)						
	10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	×	×	×	×	×	×	×
1,000	×	×	×	×	×	×	×
2,000	0·76	0·45	×	×	×	×	×
4,000	0·89	0·83	0·74	0·62	×	×	×
8,000	0·94	0·91	0·88	0·85	0·80	0·77	0·71

TABLE 13. $\varphi=10^\circ$, $c=15$, $\psi=0^\circ$

r_1 (kms.)	V_o (knots)						
	10	20	30	40	50	60	70
200	2·05	×	×	×	×	×	×
500	1·29	×	×	×	×	×	×
1,000	1·12	0·89	×	×	×	×	×
2,000	1·07	0·95	0·78	×	×	×	×
4,000	1·03	0·98	0·91	0·84	0·74	×	×

TABLE 14. $\varphi=10^\circ$, $c=15$, $\psi=30^\circ$

r_1 (kms.)	V_o (knots)						
	10	20	30	40	50	60	70
200	2·08	×	×	×	×	×	×
500	1·18	×	×	×	×	×	×
1,000	1·08	0·63	×	×	×	×	×
2,000	1·05	0·95	0·74	×	×	×	×
4,000	1·03	0·98	0·91	0·84	0·74	×	×

TABLE 15. $\varphi=10^\circ$, $c=15$, $\psi=$[illegible]0°

r_1 (kms.)	V_o (knots)						
	10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	0·79	×	×	×	×	×	×
1,000	0·95	×	×	×	×	×	×
2,000	0·98	0·84	×	×	×	×	×
4,000	0·99	0·93	0·87	0·78	0·66	×	×
8,000	0·99	0·97	0·93	0·91	0·87	0·84	0·79

TABLE 16. $\varphi=10^\circ$, $c=15$, $\psi=120^\circ$

r_1 (kms.)	V_o (knots)						
	10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	×	×	×	×	×	×	×
1,000	×	×	×	×	×	×	×
2,000	0·79	0·56	×	×	×	×	×
4,000	0·90	0·84	0·76	0·65	×	×	×
8,000	0·95	0·93	0·89	0·86	0·82	0·79	0·74

TABLE 17. $\varphi=10°$, $c=15$, $\psi=150°$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	×	×	×	×	×	×	×
1,000	×	×	×	×	×	×	×
2,000	0·74	×	×	×	×	×	×
4,000	0·86	0·79	0·71	0·56	×	×	×
8,000	0·93	0·90	0·87	0·84	0·79	0·76	0·70

TABLE 18. $\varphi=10°$, $c=15$, $\psi=180°$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	×	×	×	×	×	×	×
1,000	×	×	×	×	×	×	×
2,000	0·78	×	×	×	×	×	×
4,000	0·86	0·79	0·71	0·56	×	×	×
8,000	0·93	0·90	0·87	0·84	0·79	0·76	0·70

TABLE 19. $\varphi=20°$, $c=5$, $\psi=0°$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	0·86	×	×	×	×	×	×
1,000	0·95	0·74	×	×	×	×	×
2,000	0·98	0·92	0·84	0·76	0·60	×	×
4,000	0·99	0·96	0·92	0·90	0·87	0·83	0·78
8,000	0·99	0·97	0·96	0·95	0·94	0·92	0·90

TABLE 20. $\varphi=20°$, $c=5$, $\psi=30°$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	0·84	×	×	×	×	×	×
1,000	0·93	0·78	×	×	×	×	×
2,000	0·97	0·91	0·84	0·74	0·57	×	×
4,000	0·99	0·96	0·93	0·90	0·86	0·83	0·78
8,000	0·99	0·98	0·96	0·95	0·93	0·92	0·90

TABLE 21. $\varphi=20°$, $c=5$, $\psi=60°$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	0·80	×	×	×	×	×	×
1,000	0·91	0·75	×	×	×	×	×
2,000	0·97	0·90	0·83	0·73	×	×	×
4,000	0·98	0·95	0·92	0·89	0·85	0·81	0·76
8,000	0·99	0·98	0·96	0·95	0·93	0·92	0·90

TABLE 22. $\varphi=20°$, $c=5$, $\psi=120°$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	0·61	×	×	×	×	×	×
1,000	0·86	0·67	×	×	×	×	×
2,000	0·93	0·87	0·79	0·69	×	×	×
4,000	0·97	0·94	0·91	0·87	0·85	0·80	0·76
8,000	0·99	0·97	0·96	0·95	0·92	0·91	0·90

Table 23. φ=20°, c=5, ψ=150°

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	0·49	×	×	×	×	×	×
1,000	0·83	0·63	×	×	×	×	×
2,000	0·91	0·86	0·78	0·67	×	×	×
4,000	0·97	0·94	0·91	0·88	0·85	0·94	0·75
8,000	0·98	0·97	0·96	0·94	0·92	0·91	0·90

Table 24. φ=20°, c=5, ψ=180°

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	×	×	×	×	×	×	×
1,000	0·83	0·61	×	×	×	×	×
2,000	0·92	0·86	0·78	0·66	×	×	×
4,000	0·97	0·94	0·91	0·87	0·84	0·80	0·75
8,000	0·98	0·97	0·96	0·94	0·93	0·91	0·89

Table 25. φ=20°, c=10, ψ=0°

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	1·00	×	×	×	×	×	×
500	1·00	×	×	×	×	×	×
1,000	1·00	0·86	×	×	×	×	×
2,000	1·00	0·95	0·88	0·80	0·67	×	×
4,000	1·01	0·98	0·95	0·92	0·89	0·85	0·81
8,000	1·00	0·99	0·98	0·96	0·95	0·93	0·92

Table 26. φ=20°, c=10, ψ=30°

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	0·81	×	×	×	×	×	×
500	0·97	×	×	×	×	×	×
1,000	0·99	0·85	×	×	×	×	×
2,000	1·00	0·94	0·86	0·79	0·65	×	×
4,000	0·99	0·97	0·93	0·91	0·87	0·84	0·79
8,000	0·99	0·98	0·97	0·95	0·94	0·92	0·90

Table 27. φ=20°, c=10°, ψ=30°

Same as Table 19 where

φ=20°, c=5, ψ=0°.

Table 28. φ=20°, c=10, ψ=120°

Same as Table 24 where

φ=20°, c=5, ψ=180°.

Table 29. φ=20°, c=10, ψ=150°

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	×	×	×	×	×	×	×
1,000	0·78	0·46	×	×	×	×	×
2,000	0·90	0·83	0·75	0·63	×	×	×
4,000	0·95	0·93	0·89	0·86	0·82	0·79	0·73
8,000	0·98	0·97	0·96	0·94	0·92	0·91	0·89

Table 30. φ=20°, c=10, ψ=180°

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	×	×	×	×	×	×	×
1,000	0·76	×	×	×	×	×	×
2,000	0·89	0·83	0·75	0·62	×	×	×
4,000	0·95	0·93	0·89	0·86	0·82	0·78	0·73
8,000	0·98	0·97	0·96	0·94	0·92	0·91	0·89

Table 31. $\varphi=20°$, $c=15$, $\psi=0°$

r_1 (kms.)	V_0 (knots)						
	10	20	30	40	50	60	70
200	1·41	×	×	×	×	×	×
500	1·12	0·75	×	×	×	×	×
1,000	1·06	0·94	0·75	×	×	×	×
2,000	1·03	0·98	0·90	0·82	0·71	×	×
4,000	1·01	0·99	0·96	0·93	0·89	0·86	0·82
8,000	1·01	0·99	0·98	0·97	0·95	0·93	0·92

Table 32. $\varphi=20°$, $c=15$, $\psi=30°$

r_1 (kms.)	V_0 (knots)						
	10	20	30	40	50	60	70
200	1·25	×	×	×	×	×	×
500	1·08	×	×	×	×	×	×
1,000	1·03	0·90	0·67	×	×	×	×
2,000	1·01	0·95	0·89	0·81	0·70	×	×
4,000	1·01	0·99	0·96	0·92	0·89	0·85	0·82
8,000	1·01	0·99	0·98	0·97	0·95	0·93	0·92

Table 33. $\varphi=20°$, $c=15$, $\psi=60°$

r_1 (kms.)	V_0 (knots)						
	10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	0·94	×	×	×	×	×	×
1,000	0·96	0·82	×	×	×	×	×
2,000	0·98	0·92	0·85	0·76	0·62	×	×
4,000	0·99	0·95	0·93	0·90	0·87	0·83	0·78
8,000	1·00	0·99	0·98	0·96	0·95	0·92	0·91

Table 34. $\varphi=20°$, $c=15$, $\psi=120°$

r_1 (kms.)	V_0 (knots)						
	10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	×	×	×	×	×	×	×
1,000	0·79	0·54	×	×	×	×	×
2,000	0·90	0·83	0·75	0·62	×	×	×
4,000	0·96	0·93	0·89	0·85	0·82	0·77	0·71
8,000	0·98	0·97	0·96	0·94	0·92	0·90	0·89

Table 35. $\varphi=20°$, $c=15$, $\psi=150°$

r_1 (kms.)	V_0 (knots)						
	10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	×	×	×	×	×	×	×
1,000	0·71	×	×	×	×	×	×
2,000	0·87	0·80	0·71	0·57	×	×	×
4,000	0·95	0·91	0·88	0·85	0·82	0·77	0·73
8,000	0·97	0·95	0·94	0·93	0·91	0·89	0·86

Table 36. $\varphi=20°$, $c=15$, $\psi=180°$

r_1 (kms.)	V_0 (knots)						
	10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	×	×	×	×	×	×	×
1,000	0·71	×	×	×	×	×	×
2,000	0·86	0·79	0·70	0·54	×	×	×
4,000	0·93	0·90	0·87	0·84	0·80	0·76	0·70
8,000	0·97	0·95	0·94	0·93	0·91	0·89	0·86

TABLE 37. $\varphi=30°$, $c=5$, $\psi=0°$

r_1 (kms.)	V_c (knots) 10	20	30	40	50	60	70
200	0·73	×	×	×	×	×	×
500	0 93	0·63	×	×	×	×	×
1,000	0·97	0·88	0·77	×	×	×	×
2,000	0·98	0 95	0·90	0·86	0 79	0·73	0 61
4,000	0 99	0·97	0·96	0·94	0·[illegible]9	0·80	0·87
8,000	0·99	0·98	0·97	0·96	0 95	0·95	0·94

TABLE 38. $\varphi=30°$, $c=5$, $\psi=30°$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	1·02	×	×	×	×	×	×
500	0 98	0·76	×	×	×	×	×
1,000	0·99	0·90	0·79	×	×	×	×
2,000	0·98	0·95	0 90	0·[illegible]6	0·79	0·73	0 61
4,000	0 99	0·97	0·96	0 94	0·89	0·[illegible]9	0 87
8,000	0·99	0·98	0·97	0·96	0·95	0·95	0 94

TABLE 39. $\varphi=30°$, $c=5$, $\psi=0°$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	0·88	×	×	×	×	×	×
1,000	0·95	0·86	0·73	×	×	×	×
2,000	0·98	0·94	0·89	0·85	0·78	0·72	0 60
4,000	0·98	0·96	0·94	0 92	0 90	0·87	0 86
8,000	0·99	0·98	0·97	0·96	0·95	0·94	0·94

TABLE 40. $\varphi=30°$, $c=5$, $\psi=120°$

r_1 (kms.)	V_o (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	0·78	×	×	×	×	×	×
1,000	0·90	0·81	0·66	×	×	×	×
2,000	0·96	0·92	0 87	0·83	0·7[illegible]	0·70	0 50
4,000	0·98	0·96	0 94	0·92	0·90	0 87	0 86
8,000	0·99	0·98	0·97	0·96	0·95	0 94	0 94

TABLE 41. $\varphi=30°$, $c=5$, $\psi=150°$

r_1 (kms.)	V_o (knots). 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	0·75	×	×	×	×	×	×
1,000	0·90	0·81	0 69	×	×	×	×
2,000	0·94	0·90	0·[illegible]5	×	×	×	×
4,000	0·98	0·96	0·94	0·92	0·90	0·87	0·85
8,000	0·99	0·98	0.97	0·96	0·95	0 94	0·92

TABLE 42. $\varphi=30°$, $c=5$, $\psi=180°$

r_1 (kms.)	V_o (knots). 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	0·74	×	×	×	×	×	×
1,000	0·88	0·78	0·62	×	×	×	×
2,000	0 94	0·90	0·[illegible]5	0·81	0·74	0·66	×
4,000	0·98	0 96	0·94	0·92	0·90	0·[illegible]7	0·85
8,000	0·99	0·98	0·97	0 96	0·95	0·94	0 92

TABLE 43. $\varphi=30°$, $c=10$, $\psi=0°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	1·12	×	×	×	×	×	×
500	1·02	0·81	×	×	×	×	×
1,000	1·01	0·93	0·82	0·64	×	×	×
2,000	1·00	0·97	0·92	0·88	0·82	0·76	0·69
4,000	1·00	0·98	0·96	0·95	0·92	0·90	0·88
8,000	0·99	0·98	0·97	0·96	0·95	0·94	0·94

TABLE 44. $\varphi=30°$, $c=10$, $\psi=30°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	1·02	×	×	×	×	×	×
500	0·98	0·76	×	×	×	×	×
1,000	0·99	0·90	0·8[illegible]	0·53	×	×	×
2,000	1·00	0·97	0·92	0·88	0·82	0·76	0·69
4,000	1·00	0·9[illegible]	0·96	0·95	0·92	0·98	0·88
8,000	0·99	0·98	0·97	0·96	0·95	0·94	0·94

TABLE 45. $\varphi=30°$, $c=10$, $\psi=60°$

Same as Table 37 where
$\varphi=30°$, $c=5$, $\psi=0°$.

TABLE 46. $\varphi=30°$, $c=10$, $\psi=120°$

Same as Table 42 where
$\varphi=30°$, $c=5$, $\psi=180°$.

TABLE 47. $\varphi=30°$, $c=10$, $\psi=150°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	0·68	×	×	×	×	×	×
1,000	0·86	0·75	0·57	×	×	×	×
2,000	0·92	0·88	0·83	0·78	0·70	0·62	×
4,000	0·96	0·95	0·91	0·90	0·88	0·85	0·81
8,000	0·99	0·98	0·97	0·96	0·95	0·94	0·92

TABLE 48. $\varphi=30°$, $c=10$, $\psi=180°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	0·67	×	×	×	×	×	×
1,000	0·86	0·75	0·57	×	×	×	×
2,000	0·[illegible]2	0·88	0·83	0·78	0·70	0·62	×
4,000	0·96	0·95	0·91	0·90	0·88	0·85	0·81
8,000	0·99	0·98	0·97	0·96	0·95	0·94	0·92

TABLE 49. $\varphi=30°$, $c=15$, $\psi=0°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	1·23	×	×	×	×	×	×
500	1·08	0·89	×	×	×	×	×
1,000	1·03	0·95	0·[illegible]5	0·69	×	×	×
2,000	1·02	0·99	0·94	0·90	0·[illegible]5	0·80	0·70
4,000	1·00	0·98	0·96	0·95	0·92	0·90	0·87
8,000	0·99	0·98	0·98	0·96	0·95	0·94	0·94

TABLE 50. $\varphi=30°$, $c=15$, $\psi=30°$

r_1 (kms.)	V_0 (knots) 10	20	30	40	50	60	70
200	1·15	×	×	×	×	×	×
500	1·05	0·86	×	×	×	×	×
1,000	1·03	0·95	0·85	0·69	×	×	×
2,000	1·02	0·99	0·94	0·90	0·[illegible]5	0·80	0·70
4,000	1·00	0·98	0·96	0·95	0·92	0·90	0·87
8,000	0·99	0·98	0·98	0·96	0·95	0·94	0·94

TABLE 51 $\varphi=30°$, $c=15$, $\psi=60°$

r_1 (kms.)	V_0 (knots)						
	10	20	30	40	50	60	70
200	0·85	×	×	×	×	×	×
500	0·96	0·70	×	×	×	×	×
1,000	0·99	0·90	0·80	0·53	×	×	×
2,000	1·00	0·97	0·92	0·8[illegible]	0·82	0·76	0·66
4,000	1·00	0·9[illegible]	0·96	0·95	0·92	0·90	0·87
8,000	0·99	0·98	0·9[illegible]	0·96	0·95	0·94	0·94

TABLE 52 $\varphi=30°$, $c=15$, $\psi=120°$

r_1 (kms.)	V_0 (knots)						
	10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	0·69	×	×	×	×	×	×
1,000	0·86	0·75	0·57	×	×	×	×
2,000	0·92	0·[illegible]8	0·83	0·78	0·72	0·62	×
4,000	0·96	0·94	0·91	0·90	0·[illegible]8	0·85	0·84
8,000	0·[illegible]9	0·9[illegible]	0·97	0·96	0·95	0·94	0·94

TABLE 53. $\varphi=30°$, $c=15$, $\psi=150°$

r_1 (kms.)	V_0 (knots)						
	10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	0·53	×	×	×	×	×	×
1,000	0·82	0·63	×	×	×	×	×
2,000	0·92	0·87	0·81	0·76	0·68	0·58	×
4,000	0·96	0·94	0·91	0·90	0·88	0·85	0·84
8,000	0·99	0·98	0·97	0·96	0·95	0·94	0·94

TABLE 54. $\varphi=30°$, $c=15$, $\psi=180°$

r_1 (kms.)	V_0 (knots)						
	10	20	30	40	50	60	70
200	×	×	×	×	×	×	×
500	0·54	×	×	×	×	×	×
1,000	0·81	0·69	×	×	×	×	×
2,000	0·92	0·87	0·81	0·76	0·68	0·58	×
4,000	0·96	0·94	0·91	0·90	0·88	0·85	0·84
8,000	0·99	0·98	0·97	0·[illegible]6	0·95	0·94	0·94

× Anticyclonic motion not possible.

M has a value of more than 1 in the second column ($V_0=10$) in Tables 13, 14, 31, 32, 43, 44, 49 and 50 indicating that the trajectories are cyclonic in these cases at the places in question. In equation (4) of the second note [2], it was shown that $1/r=1/r_1\left(1-\frac{C\cos\psi}{G}\right)$ where r is the curvature of the trajectory. When $C\cos\psi$ is greater than G, the signs of r and r_1 are opposite. As r_1, refers to anticyclonic circulation, the trajectories in the cases mentioned for which M is more than 1 would be cyclonic.

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BY

C. G. Pendse

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EARTHQUAKES IN INDIA AND NEIGHBOURHOOD

By

C. G. Pendse.

(*Received on 1st February, 1947.*)

Abstract.—In this Note are listed earthquakes with epicentres in and near India, during the period 1917-1934. The data are based mainly on the material provided by the International Seismological Summary for the period under review, the intensity of an earthquake being determined by the maximum distance at which the earthquake was known to have been recorded. The positions of the epicentres are shown on a map with the help of suitable symbols. On the basis of the distribution of the epicentres in the map, the territory is divided into a number of convenient regions and a table containing the summary of the data for the different regions is given.

INTRODUCTION.

The data of the earthquakes which occurred during the period 1917-1934 and which had their epicentres in and near India are given in a condensed form in this Note. The territory selected for the sake of definiteness consists of the portion of the northern hemisphere of the globe covered by the India Meteorological Department map P_1, the limits of latitude and longitude being approximately 0° to 42° N. and 40° E. to 115° E., respectively. The basic information is taken from the following international publications :—

(1) E. F. Bellamy, "Index Catalogue of Epicentres for 1913-1930".

(2) "International Seismological Summary" for the period 1917-1934.

The intensities of the earthquakes, which have been listed, have been determined for the purpose of this Note by means of the following special scale :—

Int. Scale No.	Description.	Maximum distance (in degrees of the earth's arc) at which the shock was recorded according to the I. S. S.
I .	Feeble .	$\leq 10°$
II .	Slight .	$\leq 40°$
III .	Moderate	$\leq 100°$
IV .	Great .	$> 100°$

The special intensity scale (I, II, III, IV) employed was necessary on account of the nature of the basic information. This scale should not be confused with any of the standard earthquake intensity scales, like the Rossi-Forel scale or the Mercalli-Sieberg scale, which are used for determining the earthquake intensities at places where earthquakes are experienced and for depicting the isoseismals of individual earthquakes with the help of field reports.

This preliminary account is followed by three sections. Section 1 states the method of listing the data of earthquakes. Section 2 describes the map of epicentres which forms a part of the Note. Section 3 gives a frequency distribution table which provides a conspectus of the earthquake data.

Section 3 is followed by the list of the earthquake data and the map of epicentres.

1. THE METHOD OF LISTING THE DATA.—The serial number, latitude and longitude of an epicentre are given in the first, second and third columns respectively. The origin time(s) and intensity (intensities) of the earthquake(s) for an epicentre are indicated in columns 4-9 and column 10 respectively. 'Y.', 'M.', 'D.', 'H.', 'M.', 'S.', for any shock, refer to the year, the number of the month of the year, the day of the month, hours, minutes and seconds respectively; for the sake of brevity, the first two figures (19) for the year under 'Y.' have been omitted, so that an entry such as 25 under 'Y.' means the year 1925; the times under 'H.', 'M.', 'S.', are reckoned according to the Greenwich Mean (Civil) Time. The intensity ('Int.') of a shock

(expressed as I or II or III or IV) is given at the corresponding place in column 10.

A dot is placed wherever the corresponding figure is not available. If, in the case of a shock, the focal depth is abnormal, *i.e.*, in excess of the normal focal depth, the corresponding entry has been marked with an asterisk (*) in column 4; and in that case the depth of the focus in excess of the normal focal depth (expressed as a fraction of the radius of the earth) is given in column 11, marked "Focal depth". In the case of epicentre No. 279, the focal depths are less than the normal focal depth, and the figures, characterised by the minus sign, under column 11 give the heights (expressed as fractions of the earth's radius) of the foci above the normal depth level and the corresponding entries have been marked with two asterisks (**) under column 4.

The region of an epicentre (indicated by the letter A or B or C or D or E or F or G or H or K) is entered in column 12 entitled "Region"; the regions are introduced in Section 2.

2. The map of epicentres.—The epicentres in the list are marked in the map; the mark pertaining to a number on the map represents the corresponding epicentre in the list. In order to show on the map the principal features of epicentres as regards the intensities and focal depths of the corresponding earthquakes, the following symbolism has been adopted :—

'●' denotes an epicentre with earthquakes of normal focal depth and of intensity less than IV;

'■' denotes an epicentre having earthquakes of normal focal depth and having at least one earthquake of intensity IV;

'×' denotes an epicentre with earthquakes of abnormal focal depths and of intensity less than IV;

'⊠' denotes an epicentre having earthquakes of abnormal focal depths and having at least one earthquake of intensity IV;

'⊗' denotes an epicentre with earthquakes of normal as well as abnormal focal depths and of intensity less than IV;

'' denotes an epicentre having earthquakes of normal as well as abnormal focal depths and having at least one earthquake of intensity IV;

'' denotes the unique shallow-focus epicentre No. 279 in the list.

For a quantitative description of the data the territory is divided into regions A, B, C, D, E, F, G, H and K as shown in the map. It has been mentioned above that the region of an epicentre is entered in column 12.

3. Frequency distribution.—The data are summarised in the form of a table which is given below. In this table the symbol 'U' indicates that the intensity could not be determined in those cases; 'Epc.' and 'Eq.' stand for the total number of epicentres and the total number of earthquakes respectively; and 'N' stands for the number of 'notable' epicentres, an epicentre being classed as 'notable' if it had at least one earthquake of intensity IV.

TABLE OF EARTHQUAKE DISTRIBUTION (1917-1934).

Region.	Epc.	Eq.	No. of earthquakes of intensity.					Deep focus.		N
			I	II	III	IV	U	Epc.	Eq.	
A .	14	26	0	0	20	4	2	0	0	4
B .	5	7	0	0	7	0	0	0	0	0
C .	3	3	0	0	2	1	0	0	0	1
D .	79	204	0	10	106	77	11	0	0	57
E .	80	153	0	29	76	40	8	1	1	30
F .	64	184	23	63	60	29	9	8	28	16
G .	115	279	3	103	120	41	12	1	1	32
H .	10	21	0	2	12	6	0	0	0	4
K .	15	26	0	2	13	9	2	3	4	9
TOTAL .	385	903	26	209	416	207	44	13	34	153

LIST OF EARTHQUAKES IN INDIA AND NEIGHBOURHOOD FROM 1917 TO 1934.

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
1	0·0	70·0	23	3	6	21	6	54	III		B
2	0·0	103·0	29	12	24	15	52	42	IV		D
3	0·4	98·0	34	8	21	19	26	21	IV		D
4	0·5	100·0	18	9	22	9	54	55	IV		D
5	0·8	98·3	34	9	21	12	38	49	IV		D
6	1·0	97·5	26	8	3	19	41	12	IV		D
			29	3	26	8	25	12	III		
7	1·0	99·0	17	6	21	17	42	33	III		D
8	1·0	101·0	23	7	27	11	24	54	IV		D
9	1·5	90·0	31	7	27	16	29	1	IV		C
10	1·5	110·0	18	1	16	2	33	5	IV		K
			*21	9	20	20	21	15	III	0·050	
11	2·0	66·5	32	3	26	7	8	56	III		B
12	2·0	83·0	19	10	4	17	50	0	III		C
13	2·0	96·0	20	3	17	18	36	50	IV		D
			23	4	13	2	26	30	IV		
14	2·4	98·8	21	4	1	4	6	40	IV		D
			24	7	21	0	36	18	IV		
			29	9	9	3	28	15	IV		
15	2·8	96·0	26	9	23	18	31	48	IV		D
			27	3	19	20	30	30	III		
			28	12	14	1	58	4	IV		

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
15 *contd.*	2·8	96 0	29	6	29	1	39	36	III		
			31	3	5	17	55	8	IV		
16	3·0	65·0	26	12	2	16	41	47	III		B
			30	8	23	15	7	28	III		
17	3·0	89·0	22	10	1	17	26	8	III		C
18	3·0	97·8	28	12	10	4	33	33	IV		D
19	3·5	62·7	32	2	21	13	21	0	III		B
20	3·5	97·5	*34	5	1	7	5	2	III	0·0225	D
21	4·0	94·1	30	2	27	2	15	16	IV		D
			33	6	1	17	19	57	III		
22	4·0	97·0	21	1	26	17	55	8	IV		D
23	4·2	96·0	34	7	31	10	58	52	IV		D
			34	7	31	11	49	24	IV		
24	4·5	61·5	27	8	18	1	50	45	III		B
			28	7	6	0	48	0	III		
25	4·5	95·5	18	2	12	3	0	43	IV		D
26	4·6	97·5	32	6	16	1	18	50	IV		D
27	4·8	96·8	17	11	4	12	3	30	IV		D
			25	3	19	15	37	55	IV		
			28	1	15	2	55	18	IV		
..			34	5	12	20	26	36	III		
28	4·9	94·8	29	12	9	6	49	49	IV		D
29	5·0	99·0	31	1	20	15	26	32	IV		D

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
30	5·0	110·0	*20	2	26	23	4	3	II	0·050	K
			*20	5	27	5	49	12	IV	0·050	
31	5·5	93·0	29	3	25	14	54	24	III		D
			29	6	8	6	10	40	III		
32	6·0	99·5	27	6	16	.	.		.		D
33	6·6	96·6	33	5	16	.		.			D
34	7·0	94·0	21	3	5	6	24	8	IV		D
			24	1	24	18	34	42	III		
			28	7	27	15	22	54	IV		
35	8·0	94·0	27	5	17	.			.		D
			30	7	17	14	34	44	IV		
			30	12	13	16	28	27	III		
			31	8	8	4	7	8	IV		
			34	5	22	1	21	47	III		
36	8·5	93·6	32	9	20	15	43	32	IV		D
37	8·8	93·9	32	12	11	4	26	1	IV		D
38	9·0	94·0	30	9	30	13	5	0	III		D
39	9·0	110·0	18	8	16	7	22	20	III		K
40	9·5	60·0	25	2	2	18	44	24	III		A
			29	1	1	13	38	5	IV		
41	10·0	56·5	28	7	4	17	53	28	III		A
42	10·2	92·8	25	6	28	13	41	35	IV		D
43	10·5	92·5	25	5	13	23	54	24	IV		D

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
44	11·0	57·0	26	1	5	10	3	14	III		A
			27	11	5	21	56	41	III		
			32	2	12	0	58	17	IV		
			32	2	12	..		..	.		
			32	2	12	.	..	..	..		
45	11·5	96·0	31	2	13	22	17	30	III		D
46	12·0	93·5	29	8	1	5	1	48	IV		D
			31	2	28	22	25	51	III		
47	12·0	95·0	17	1	20	23	48	44	IV		D
			18	1	18	10	35	5	IV		
			18	9	7	23	31	51	III		
			18	12	16	3	3	20	IV		
			22	10	17	6	37	54	IV		
			22	10	17	9	56	0	III		
			22	10	17	.	..	..	..		
			22	10	17	..	.	..	..		
			25	4	14	1	34	10	III		
48	12·7	94·5	26	7	6	21	20	30	IV		D
			29	4	30	18	48	36	IV		
49	13·0	90·0	17	7	4	22	9	30	IV		H
50	13·0	93·0	28	5	19	3	28	36	IV		D
51	13·5	50·0	23	12	10	23	53	28	III		A
			27	2	26	23	54	24	III		

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
52	13·5	52·0	28	9	18	19	52	27	IV		A
			31	6	23	12	12	53	III		
53	13·6	55·6	32	8	14	12	36	14	III		A
54	14·0	49·0	34	9	5	2	21	3	III		A
55	14·0	60·0	17	12	5	12	48	40	III		A
			18	12	16	20	20	10	III		
56	14·0	109·0	24	12	26	23	40	30	III		K
			26	8	15	9	53	45	IV		
57	14·2	53·8	29	3	16	3	22	3	III		A
			29	3	16	12	30	40	III		
			32	6	11	8	32	58	III		
58	14·5	52·0	24	4	20	14	26	54	IV		A
59	14·5	53·0	28	3	19	10	1	54	III		A
60	14·5	54·0	29	4	28	4	58	32	III		A
61	15·0	59·7	31	6	24	23	47	12	III		A
62	15·0	88·5	27	7	29	0	3	5	IV		H
63	15·0	97·0	30	12	3	15	42	14	II		D
64	15·0	111·0	17	2	5	12	18	52	IV		K
			21	11	22	20	7	30	III		
65	15·5	56·5	25	2	1	15	56	48	III		A
			27	10	23	4	2	12	III		
			28	6	11	6	11	0	III		
66	15·5	92·5	26	5	29	22	37	25	III		D

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
66 *contd.*	15·5	92·5	26	7	12	22	12	30	III		
			27	4	28	2	4	42	III		
			31	11	30	17	1	41	III		
67	15·5	109·0	19	11	16	3	5	33	IV		K
68	15·9	83·7	18	5	19	0	25	22	III		H
69	17·3	96·5	30	5	5	13	45	58	IV		D
			30	12	3	16	36	20	III		
70	18·0	84·0	17	4	17	13	31	45	III		H
71	18·0	97·0	17	4	12	2	54	35	IV		D
			19	9	8	4	8	0	III		
			21	9	12	5	9	48	III		
			29	12	15	19	54	28	III		
			31	8	10	10	21	40	II		
72	18·2	96·4	30	12	3	18	51	51	IV		D
			31	9	6	5	38	12	III		
73	19·0	96·0	33	7	3	15	9	10	III		D
74	19·0	109·0	20	5	27	5	49	30	IV		K
75	19·8	103·3	18	3	22	5	51	50	IV		K
			19	12	9	20	23	15	III		
76	20·0	98·0	22	5	2	11	10	45	IV		D
77	20·0	101·5	25	12	22	5	5	25	IV		K
			25	12	23	23	4	12	III		
			26	3	29	15	52	55	III		

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
77 *contd.*	20·0	101·5	30	5	16	2	16	0	III		
			34	2	12	11	30	58	III		
78	20·8	106·6	26	9	11	17	2	30	III		K
79	21·0	60·0	30	10	9	21	30	30	III		G
80	21·0	97·0	22	12	24	0	6	26	III		D
			29	8	8	12	57	13	IV		
81	21·5	68·0	27	11	18	11	1	36	III		G
82	22·0	63·0	25	5	28	3	19	15	III		G
83	22·0	90·0	27	8	25	22	56	38	III		H
84	22·0	95·5	32	8	14	7	10	37	III		D
85	22·0	100·5	23	7	1	7	54	55	IV		D
86	22·2	93·2	20	8	15	6	59	8	IV		F
			21	3	10	..	..	..	.		
87	22·6	93·4	23	8	10	15	58	6	IV		F
88	22·7	99·0	23	6	22	6	44	30	IV		D
			23	6	22	12	6	4	III		
			27	7	20	19	6	0	III		
89	23·0	95·0	24	9	2	2	3	0	III		D
			26	9	8	15	49	30	III		
			28	10	12	7	26	9	III		
90	23·0	96·0	30	9	13	17	58	58	III		D
91	23·0	97·0	26	11	21	11	14	45	III		D
			30	12	4	6	18	39	III		

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
92	23·5	102·5	29	2	9	1	55	40	III		D
			34	1	12	13	31	57	IV		
93	24·0	64·5	33	7	7	7	30	57	III		G
			34	4	19	23	27	3	II		
94	24·0	82·3	27	6	2	16	37	24	IV		H
95	24·0	97·0	31	7	29	17	9	45	III		D
			33	11	19	9	8	33	III		
96	24·3	97·9	30	11	4	15	38	2	IV		D
			31	3	15	15	15	5	III		
			33	5	12	16	10	43	III		
97	24·5	63·4	32	4	18	11	23	27	III		G
			32	4	18	..	..	..	..		
98	24·5	94·5	26	8	18	23	58	48	III		D
			27	5	20	10	51	0	III		
99	24·7	63·0	27	12	14	7	50	18	II		G
100	25·0	51·5	29	10	29	8	57	35	III		G
101	25·0	68·0	20	7	10	..	..	..	..		G
			21	10	26	7	5	35	III		
			21	10	26	23	2	40	III		
102	25·0	70·7	21	2	11	..	..	..	..		G
103	25·0	77·5	26	12	31	16	53	45	III		H
			29	4	10	23	53	0	III		
			30	6	25	0	49	0	III		

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
104	25·0	93·0	24	1	30	0	5	24	IV		D
			26	10	23	14	30	18	III		
105	25·0	93·5	30	7	11	7	6	34	III		D
106	25·0	100·5	25	3	16	14	42	6	IV		D
			25	3	16	23	50	26	IV		
			30	5	14	19	48	22	III		
			30	12	9	0	27	30	III		
			30	12	12	2	53	12	III		
			31	1	31	20	42	50	II		
107	25·0	102·0	29	3	22	3	3	54	IV		D
			34	3	3	0	34	5	II		
108	25·0	108·5	26	11	23	20	37	8	III		K
109	25·1	94·7	34	6	2	5	54	27	IV		D
110	25·2	56·8	24	12	11	23	1	0	III		G
			28	9	20	14	59	0	II		
111	25·3	93·8	30	9	22	14	19	14	IV		D
112	25·4	96·8	31	1	27	20	9	21	IV		D
			31	1	30	3	32	38	III		
			31	2	11	19	47	41	III		
			31	4	7	0	15	47	III		
			31	5	20	5	10	6	III		
			32	2	5	13	43	34	III		
			32	2	5	..	..	..	..		

No.	Lat. N °	Long. E. °	Y.	M.	D.	H	M.	S.	Int.	Focal depth.	Region.
112	25·4	96·8	32	5	26	5	12	26	III		
113	25·5	91·5	23	9	9	22	3	42	IV		D
114	25·5	92·5	32	3	6	0	18	4	II		D
			32	3	6	.	..	.	.		
			32	3	27	8	44	45	III		
115	25·5	93·5	27	2	13	3	33	20	III		D
			28	11	15	15	34	56	II		
116	25·5	98·0	29	1	19	11	19	33	III		D
			29	6	10	0	18	4	III		
			29	6	12	14	30	4	III		
			29	6	19	19	20	45	III		
			30	2	28	22	49	10	III		
			30	4	28	18	34	41	IV		
			30	6	5	16	27	4	III		
			30	8	6	7	28	30	III		
			30	9	1	5	18	3	III		
			31	2	10	1	22	54	IV		
			33	8	4	17	32	40	III		
117	25·5	98·5	29	9	9	18	57	45	III		D
			29	10	16	20	27	24	IV		
			29	10	18	10	42	35	III		
			30	9	21	23	4	17	IV		
			30	9	22	4	54	50	III		

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
117 *contd.*	25·5	98·5	30	9	22	7	11	27	III		
			30	9	25	18	33	40	III		
			30	10	7	2	27	20	III		
			30	10	10	0	37	18	III		
			30	12	2	7	1	26	IV		
			31	4	2	0	27	46	III		
			31	7	25	12	40	6	III		
			31	10	18	7	6	48	III		
			32	1	3	7	50	30	III		
			32	1	3	.		.	..		
			34	1	19	12	33	14	III		
			34	4	12	9	10	40	III		
118	25·7	90·5	33	3	6	13	5	38	IV		D
119	25·8	90·2	30	7	2	21	3	34	IV		D
			30	7	3	0	19	5	III		
			30	7	3	6	1	21	II		
			30	7	4	18	54	44	III		
			30	7	4	21	34	0	III		
			30	7	8	4	32	24	III		
			30	7	8	9	43	0	III		
			30	7	13	14	0	12	III		
			31	2	7	15	3	14	II		
			32	3	24	16	8	44	III		

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
119 *contd.*	25·8	90·2	32	3	24	..		..	.		
120	25·8	95·7	32	8	14	4	39	39	IV		D
			32	8	14	4	40	7	IV		
			33	12	4	14	40	14	IV		
121	26·0	54·8	31	5	5	6	42	19	III		G
			31	5	5	11	40	7	III		
			31	5	5	14	10	45	III		
			31	5	7	0	45	40	III		
			34	2	16	7	59	53	II		
122	26·0	96·0	24	2	14	18	55	30	III		D
			24	8	1	14	42	56	III		
			26	8	6	13	17	48	III		
			27	3	15	16	56	27	III		
			29	10	29	18	33	3	III		
123	26·0	98·4	33	8	11	8	54	7	IV		D
			33	8	11	..	..	.	.		
			33	8	12	7	29	10	III		
			33	11	5	20	27	20	III		
124	26·0	102·5	27	3	14	17	37	32	IV		D
125	26·0	114·0	17	1	27	..	.	.	..		K
			19	12	9	20	28	6	II		
126	26·2	66·7	34	5	1	3	40	45	III		G
127	26·4	62·3	*29	9	3	12	7	32	IV	0·020	G

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
127—*contd.*	26·4	62·3	32	2	4	21	18	16	III		
			32	2	4	.	..		.		
128	26·5	52·5	34	3	10	2	3	18	II		G
			34	3	18	22	19	33	II		
			34	3	18	22	44	37	II		
129	26·5	81·5	25	11	6	19	20	45	III		H
130	26·5	92·0	18	7	8	10	22	7	IV		E
			32	11	9	18	30	16	III		
131	26·5	99·0	28	12	31	7	33	36	III		D
			30	3	23	19	24	25	III		
132	26·6	86·8	34	1	15	8	43	25	IV		E
			34	1	19	18	49	54	II		
133	26·8	66·5	30	9	29	13	29	0	III		G
134	27·0	52·5	34	3	19	3	28	28	III		G
135	27·0	96·0	26	5	10	8	18	55	IV		D
			27	7	15	21	10	30	III		
			28	7	9	15	47	40	III		
			28	8	30	12	12	20	III		
136	27·0	100·0	25	10	14	17	5	18	III		[illegible]
			25	10	15	12	36	12	IV		
			26	12	5	19	40	36	III		
			26	12	5	19	44	8	III		
			31	6	25	0	40	12	III		

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
137	27·0	103·5	25	4	16	5	32	15	III		D
138	27·2	59·5	26	5	19	21	13	44	III		G
139	27·5	53·3	34	8	31	0	40	2	II		G
140	27·5	53·8	24	6	30	3	41	12	IV		G
			27	11	16	1	27	0	II		
141	27·5	55·0	25	9	24	4	38	36	IV		G
			26	4	23	1	31	30	III		
			29	10	29	5	53	30	III		
			29	10	29	10	32	36	III		
			29	10	29	11	48	20	III		
			29	11	20	19	56	58	III		
			30	5	11	22	35	50	IV		
			30	5	12	0	21	15	IV		
			30	5	13	20	14	14	III		
			30	8	17	12	29	32	IV		
			30	8	23	10	53	18	IV		
			30	9	5	16	20	38	III		
			31	11	16	8	25	5	II		
142	27·5	57·5	33	2	21	19	3	5	III		G
			33	2	26	5	9	42	II		
			34	2	26	14	47	19	II		
143	27·5	62·6	34	6	13	22	10	24	IV		G
144	27·5	63·6	19	10	24	20	32	15	III		G

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
145	27·5	98·5	31	5	27	0	43	33	III		D
			31	8	11	17	40	49	III		
			33	7	19	20	48	33	II		
146	27·5	100·0	33	6	7	11	46	12	IV		D
147	27·5	106·0	29	11	6		..		..		K
			30	9	23	12	5	7	III		
148	27·6	57·8	28	4	30	11	19	48	III		G
			28	8	14	0	9	9	III		
149	28·0	54·0	30	4	15	9	56	27	III		G
150	28·0	62·0	27	7	7	20	6	21	IV		G
			29	3	26	14	0	10	III		
151	28·0	86·0	34	1	16	8	43	25	IV		E
152	28·0	91·0	28	2	6	0	23	12	II		E
153	28·3	98·0	31	8	4	5	40	8	III		E
			31	10	2	14	18	28	II		
154	28·5	56·0	27	5	9	10	31	40	IV		G
			27	7	24	13	23	12	III		
155	28·5	66·3	28	10	15	14	19	32	IV		G
			28	10	21	13	11	25	III		
156	28·5	69·0	31	8	26	19	29	26	III		G
			31	8	28	0	42	20	III		
			31	9	30	11	14	51	III		
157	28·7	51·9	27	7	30	4	0	40	II		G

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
157—*contd.*	28·7	51·9	28	4	15	10	9	28	III		
			28	8	26	23	16	21	II		
			28	8	27	3	37	54	III		
			28	8	27	4	19	57	III		
			29	7	16	19	43	15	III		
			29	10	2	11	51	54	II		
			30	2	15	19	7	6	III		
			30	7	8	17	15	42	III		
158	29·0	104·0	17	7	30	23	54	5	IV		D
			25	10	29	19	31	40	III		
159	29·3	98·7	29	5	24	18	37	44	IV		E
160	29·4	51·4	30	9	2	18	58	52	III		G
			30	10	18	1	2	20	III		
			31	7	28	17	36	32	III		
161	29 5	56·0	23	9	22	20	47	33	IV		G
			23	9	23	3	18	58	IV		
			24	1	18	14	56	20	III		
162	29·5	59·5	23	9	14	8	10	30	IV		G
			25	7	11	21	52	22	III		
163	29·5	80·0	33	5	18	10	24	12	II		E
164	29·5	91·5	24	8	13	23	57	42	IV		E
165	29·5	95·0	29	3	25	3	46	54	III		E
166	29·5	101·0	26	8	11	5	47	30	III		E

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
166—*contd.*	29·5	101·0	27	7	2	20	38	36	III		
			31	7	27	6	0	0	II		
167	29·6	87·8	18	2	4	17	54	49	IV		E
			23	4	24	22	3	6	III		
			26	12	4	11	15	23	IV		
			27	9	29	6	14	55	II		
168	29·8	67·3	31	8	27	15	27	25	IV		G
			31	8	28	19	40	8	III		
			31	8	28	21	24	13	III		
			31	9	3	17	10	47	III		
			31	10	3	10	35	10	III		
169	30·0	51·0	25	7	30	18	43	10	III		G
			25	12	18	5	53	20	III		
170	30·0	57·5	34	1	2	20	55	45	III		G
171	30·0	64·0	28	8	19	3	54	36	III		G
172	30·0	71·0	17	12	1	9	47	15	III		H
			18	11	29	10	41	50	III		
			19	5	23	6	10	38	IV		
			19	5	23	18	8	40	III		
			19	6	1	12	46	20	III		
			19	6	15	18	49	4	IV		
			28	9	1	6	8	52	IV		
			31	9	7	21	13	3	II		

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
173	30·0	83·0	27	11	29	11	34	26	III		E
174	30·0	85·0	24	5	27	14	32	15	II		E
			25	12	15	7	44	30	III		
175	30·0	89·2	32	3	25	4	29	32	III		E
176	30·0	99·0	23	10	20	3	18	48	IV		E
177	30·0	100·0	30	8	24	10	51	20	III		E
178	30·2	67·7	31	8	24	21	35	30	IV		G
			31	8	24	23	30	15	III		
			31	8	25	0	31	8	II		
			31	8	25	0	54	9	II		
			31	8	25	3	6	25	III		
			31	8	25	15	45	35	III		
			31	8	25	18	52	57	III		
			31	8	28	3	18	7	II		
			31	9	26	..	..	..	..		
179	30·4	84·0	31	6	18	12	58	36	III		E
180	30·5	51·7	34	2	4	13	27	20	IV		G
			34	3	13	23	33	38	II		
181	30·5	54·5	29	1	21	15	48	5	II		G
			29	8	11	10	8	16	II		
			31	5	3	19	22	30	III		
			31	9	2	3	28	23	II		
182	30·5	69·0	27	5	21	8	4	45	III		G

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
182—*contd.*	30·5	69·0	28	12	12	1	25	30	III		
			28	12	14	0	28	20	IV		
183	30·5	80·5	26	7	27	7	23	36	IV		E
			27	10	8	10	34	28	IV		
184	30·5	82·0	18	4	28	11	12	40	III		E
185	30·5	91·0	20	10	14	.					E
			*24	10	8	20	32	52	IV	0·010	
186	30·5	102·0	26	11	22	19	8	12	III		E
187	30·7	58·4	32	9	8	7	25	39	III		G
188	30·9	89·1	34	12	18	11	22	24	III		E
			34	12	21	6	34	42	II		
189	31·0	96·0	25	8	26	16	8	30	III		E
			27	7	7	7	39	12	III		
			31	1	29	17	10	31	II		
			32	3	6	21	43	50	III		
			32	3	6	.	..	..	..		
190	31·0	114·0	17	1	24	0	48	12	IV		K
191	31·2	61·6	23	11	29	3	36	36	III		G
			30	9	6	21	36	5	II		
192	31·2	70·3	23	10	1	8	16	25	IV		G
			23	10	2	11	22	20	III		
			23	10	15	3	49	10	III		
			27	1	30	8	54	0	IV		

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
192—*contd.*	31·2	70·3	33	8	11	13	49	49	II		
193	31·3	88·8	34	12	14	20	42	36	II		E
194	31·5	47·5	29	2	5	1	57	13	II		G
195	31·5	89·0	34	12	15	1	57	44	IV		E
			34	12	21	12	39	7	III		
196	31·5	100·5	19	5	29	10	59	45	IV		F
			23	3	24	12	40	10	IV		
197	31·7	77·0	29	1	14	9	45	21	II		E
			30	5	11	11	30	36	III		
198	31·7	103·4	33	8	25	7	50	33	IV		F
			33	8	25	11	38	53	II		
			33	8	25			..	..		
			33	8	25			.	..		
199	32·0	49·0	31	8	29	12	30	51	II		G
200	32·0	56·1	33	11	28	11	9	26	IV		G
			33	11	28	.	..	..	..		
			34	1	1	21	55	55	II		
201	32·0	57·0	23	5	25	22	21	25	IV		G
			29	5	17	19	33	33	II		
202	32·0	59·0	28	3	8	18	13	54	III		G
203	32·0	74·0	19	9	5	7	52	20	III		H
			24	4	3	2	48	30	II		
204	32·0	88·0	24	2	9	22	54	5	IV		E

No.	Lat. N. °	Long E °	Y.	M.	D	H.	M.	S.	Int.	Focal depth.	Region.
205	32·0	100·0	19	8	25	19	55	15	III		E
			30	4	28	12	59	27	III		
206	32·2	55·8	33	12	12	5	21	46	II		G
			33	12	14	18	51	49	III		
207	32·3	93·0	30	9	24	3	22	20	III		E
			34	6	23	5	19	58	III		
208	32·5	43·7	30	4	3	12	8	40	III		G
209	32·5	47·0	30	4	3	6	32	58	III		G
210	32·5	53·0	28	9	18	8	7	50	III		G
			31	1	4	20	10	48	III		
211	32·5	64·0	28	9	10	17	28	51	III		G
			31	9	10	22	27	8	II		
212	32·5	97·5	23	8	7	14	23	28	IV		E
			24	1	26	18	24	20	II		
			30	9	29	9	58	42	II		
213	32·7	67·3	33	10	16	4	34	52	III		G
214	32·8	84·3	31	8	2	18	4	39	II		E
			31	8	2	18	16	55	II		
215	32·9	69·3	31	6	2	17	36	55	II		G
			31	6	9	0	29	22	III		
216	33·0	50·0	22	3	21	16	56	12	IV		G
217	33·2	71·4	24	9	12	0	9	40	II		G
			24	9	12	8	59	30	II		

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int	Focal depth.	Region.
218	33·5	46·5	17	7	15	17	58	40	IV		G
			17	7	15	21	22	10	II		
			17	7	24	16	12	40	III		
			17	11	23	4	17	30	III		
			17	11	24	19	57	40	III		
			20	5	25	11	39	55	III		
			27	11	12	14	45	40	IV		
			30	12	5	5	56	48	II		
219	33·5	48·0	27	11	15	14	39	12	III		G
			29	10	27	16	42	57	III		
			32	1	22	0	49	18	II		
			32	1	22	.	..	..			
220	33·5	54·0	27	7	22	20	33	8	III		G
221	33·5	81·0	32	3	4	23	50	55	IV		E
			32	3	4	.	..	.	..		
			32	3	4	..	..	..	.		
222	33·6	82·0	34	10	19	20	58	20	III		E
223	33·7	49·4	29	7	15	7	44	7	IV		G
			31	7	8	13	13	13	II		
224	34·0	61·5	25	5	2	2	57	0	II		G
225	34·0	73·0	27	6	27	8	12	15	III		G
			27	6	29	22	0	50	II		
226	34·0	96·0	19	3	2	16	56	50	III		E

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
227	34·2	48·0	32	3	15	10	18	10	III		G
			32	3	15	.			. .		
228	34·2	72·0	27	9	5	20	10	30	III		G
			27	9	30	18	40	6	III		
			28	5	2	14	3	13	II		
229	34·2	77·5	17	5	9	21	45	50	IV		E
			21	11	11	1	18	45	III		
230	34·4	105·8	30	7	23	18	53	16	III		E
231	34·5	41·8	18	4	25	2	22	35	IV		G
			19	8	31	2	32	48	III		
232	34·5	57·1	18	3	24	23	14	54	IV		G
233	34·7	54·0	27	7	22	3	54	54	IV		G
			27	7	22	8	37	30	III		
			27	7	22	20	33	30	II		
			27	7	23	20	17	46	III		
			27	7	23	22	40	18	IV		
			27	7	27	20	41	42	II		
234	34·8	46·0	23	6	18	4	18	40	II		G
235	35·0	44·0	26	4	2	11	56	0	III		G
			29	8	7	20	22	25	II		
236	35·0	69·0	20	2	27	3	51	36	IV		F
			*21	5	20	0	43	10	IV	0·030	
			*25	3	8	11	27	42	III	0·030	

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int	Focal depth.	Region.
236—*contd.*	35·0	69 0	26	3	18	6	31	45	II		
			26	3	22	16	24	0	IV		
			*27	7	15	3	46	30	IV	0·030	
			*27	10	2	3	7	26	III	0·030	
			28	6	24	4	34	22	IV		
237	35·0	71·5	28	11	14	4	32	54	III		G
238	35·0	78·0	26	8	6	20	36	30	III		E
			26	8	6	22	45	46	IV		
			29	11	16	13	3	36	II		
239	35·0	89·0	26	7	15	18	25	40	III		E
240	35·0	90·5	19	6	28	10	26	53	III		E
			20	5	2	8	27	50	IV		
			20	5	2	14	46	40	IV		
			25	8	31	9	58	0	IV		
			26	6	4	6	50	45	IV		
			26	6	4	8	3	0	III		
			26	6	6	6	49	0	III		
241	35·0	98·0	31	7	29	11	35	32	III		E
242	35·1	57·8	33	10	5	13	29	53	IV		G
			33	10	5	..	.	..	.		
243	35·1	70·9	34	12	27	13	37	27	II		F
244	35·1	102·1	31	12	6	23	1	3	III		E
245	35·2	81·1	30	9	1	17	43	17	III		E

No.	Lat. N. °	Long. E. °	Y.	M.	D	H.	M.	S.	Int.	Focal depth.	Region.
246	35·4	65·3	34	4	3	11	26	44	II		G
247	35·5	48·0	24	11	8	9	5	0	III		G
			24	11	8	17	45	20	III		
			24	11	10	21	8	56	III		
			24	11	10	21	54	56	III		
			24	11	11	15	53	40	III		
			24	11	12	9	28	20	II		
			27	6	15	6	46	10	II		
248	35·5	55·0	23	9	17	7	9	4	IV		G
			24	7	3	8	8	30	II		
			24	7	3	8	18	50	III		
			27	7	29	11	33	12	II		
			28	4	14	13	16	33	II		
249	35·5	59·0	28	8	21	19	1	52	IV		G
250	35·5	77·0	23	9	30	23	10	15	III		E
			27	7	24	14	0	24	III		
251	35·5	104·0	20	12	28	3	16	30	IV		E
			24	4	21	16	12	25	III		
252	35·6	43·2	31	10	13	7	36	42	II		G
253	35·7	81·0	20	10	12	6	54	40	IV		E
			24	11	6	7	46	0	III		
254	35·79	105·74	20	12	16	12	5	43	IV		E
			20	12	25	11	33	8	IV		

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M	S.	Int.	Focal depth.	Region.
255	35·8	52·1	30	10	2	15	33	12	III		G
			30	10	7	20	53	6	II		
256	36·0	71·0	30	12	16	8	19	25	II		F
			31	5	16	7	15	14	II		
			*31	8	15	4	1	4	III	0·025	
257	36·0	78·0	30	5	17	17	11	10	II		E
258	36·0	84·5	26	7	17	19	14	12	III		E
			27	2	5	0	0	36	II		
259	36·0	86·0	30	11	30	0	35	0	III		E
260	36·0	92·5	29	12	7	9	54	45	II		E
261	36·0	102·0	28	3	7	22	43	14	IV		E
			28	5	5	13	40	50	III		
262	36·0	103·0	28	3	21	3	53	18	II		E
263	36·2	69·5	33	5	21	17	53	55	II		F
264	36·2	70·7	*34	11	18	3	21	23	IV	0·020	F
265	36·3	44·9	32	5	7	14	54	15	II		G
266	36·3	53·5	32	5	20	19	16	18	III		G
			32	5	20	..	..	..	..		
267	36·3	69·4	31	9	14	3	32	8	IV		F
			32	3	9	1	11	50	II		
			32	3	9	..	..	..	..		
			33	12	2	2	15	21	III		
268	36·3	71·0	34	11	15	23	14	48	III		F

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
269	36·5	49·0	27	10	31	6	23	0	II		G
270	36·5	65·5	28	2	25	17	23	42	III		G
			28	8	2	1	31	14	II		
			29	4	24	4	59	15	II		
271	36·5	70·5	*21	11	15	20	36	30	IV	0·030	
			*25	5	14	7	10	48	III	0·020	
			*25	9	23	20	12	15	III	0·020	
			*26	5	26	9	40	36	II	0·020	
			*27	4	24	11	20	20	III	0·020	
			28	1	21	15	4	50	III		
			*28	8	10	15	33	37	III	0·035	
			*29	2	1	17	14	12	IV	0·025	
			*29	3	3	3	10	50	III	0·035	
			*29	12	10	17	55	3	II	0·025	
			*30	9	11	17	20	10	III	0·025	
			32	2	9	2	19	44	II		
			32	2	9	..	..	..	..		
			32	4	30	10	52	35	III		
			*33	1	9	2	1	47	IV	0·025	
			*33	1	9	..	..	..	.	0·025	
			*33	1	20	12	12	13	II	0·025	
			34	1	16	23	20	20	II		
			*34	7	22	19	57	0	IV	0·025	

No.	Lat. N. °	Long E. °	Y.	M	D.	H.	M	S	Int.	Focal depth	Region.
271—*contd.*	36·5	70·5	34	9	26	1	7	2	III		
2 2	36·5	75·0	28	4	12	15	25	48	III		E
			29	9	24	13	51	55	III		
273	36·5	96·0	30	3	26	11	14	40	III		E
274	36·6	77·8	33	7	15	22	21	36	II		E
275	36·7	63·0	25	8	6	7	15	24	II		G
			25	11	23	14	38	22	II		
			27	7	11	16	12	10	II		
276	36·7	72·2	34	10	25	10	20	28	I		F
277	36·8	69·5	*22	12	6	13	55	26	IV	0·020	F
			*25	12	18	18	10	16	III	0·030	
			27	10	7	21	34	25	III		
			31	11	4	15	21	31	II		
			33	6	23	20	50	50	II		
			34	6	18	3	26	42	II		
278	36·8	97·4	33	3	31	21	59	36	III		E
279	36·8	102·8	**27	5	22	21	43	0	III	—0·005	E
			**27	5	22	22	32	32	IV	—0·005	
			**27	5	23	2	45	40	IV	—0·005	
			**27	5	23	13	51	6	III	—0·005	
			**28	3	20	2	23	28	III	—0·005	
			**28	3	21	3	53	24	II	—0·005	
280	37·0	44·0	30	5	6	7	3	22	III		G

No	Lat. N °	Long. E °	Y	M	D	H.	M	S	Int	Focal depth.	Region
280—*contd.*	37·0	44·0	30	5	6	22	34	27	IV		
			30	5	7	4	47	46	I		
			30	5	7	4	58	40	II		
			30	5	7	5	24	24	I		
			30	5	7	5	42	30	II		
			30	5	7	9	29	30	II		
			30	5	7	10	58	25	II		
			30	5	7	11	31	42	II		
			30	5	9	1	43	0	II		
			30	5	10	21	43	22	III		
			30	5	10	23	59	20	II		
			30	5	21	13	50	51	II		
			30	7	9	4	35	49	II		
			30	8	21	6	55	20	II		
281	37·0	53·0	24	9	27	10	12	10	II		G
282	37·0	58·5	29	7	13	7	36	25	II		G
			30	10	6	18	8	18	II		
			31	8	8	8	54	24	II		
283	37·0	71·0	*31	10	5	22	31	29	IV	0·020	F
			34	10	27	4	57	43	I		
284	37·0	72·0	*24	10	13	16	17	36	IV	0·030	F
			*25	6	20	13	4	4	III	0·040	
			30	5	24	9	25	5	II		

No.	Lat. N	Long. E	Y	M.	D	H	M	S	Int.	Focal depth.	Region.
284—*contd.*	37·0	72·0	30	9	5	10	13	56	IV		
			*31	1	20	9	27	30	IV	0·030	
			*33	5	27	22	42	3	III	0·030	
285	37·0	79·9	33	10	19	5	55	13	II		E
286	37·0	81·0	23	12	16	11	48	20	III		E
287	37·3	44·8	30	5	8	15	35	24	IV		G
			30	5	8	23	36	22	II		
			30	8	3	22	5	51	II		
			31	12	24	23	0	5	III		
288	37·3	85·3	24	7	3	4	40	0	IV		E
			24	7	5	15	1	54	IV		
			24	7	11	19	44	33	IV		
			24	7	15	21	38	0	III		
			26	3	3	18	6	27	IV		
289	37·5	45·5	29	11	5	10	6	4	III		G
			30	5	7	13	47	48	II		
			30	5	8	5	29	30	III		
			30	5	8	14	23	32	II		
			30	5	8	15	5	21	II		
			30	5	23	9	48	20	III		
			30	5	29	17	14	55	III		
			31	5	12	10	25	10	III		
			31	7	4	21	0	54	II		

No.	Lat. N °	Long. E	Y	M	D.	H	M.	S	Int	Focal depth	Region.
290	37·5	55·0	28	4	26	15	39	50	II		G
291	37·5	60·0	29	12	24	19	54	35	II		G
292	37·5	70·5	17	4	21	0	49	18	IV		F
			23	7	16	13	23	36	III		
			23	7	29	9	37	20	III		
			24	9	17	10	20	30	III		
			29	7	10	9	1	57	II		
			29	12	29	0	58	53	I		
			30	9	23	10	15	21	III		
			31	1	7	3	49	36	II		
			32	2	14	20	30	25	II		
			32	2	14		..	..	..		
			33	7	25	13	38	23	II		
			34	4	19	23	27	3	II		
			34	9	18	7	7	13	II		
293	37·5	90·0	23	11	21	13	34	0	III		E
			24	6	17	16	26	36	III		
294	37·5	99·0	27	3	15	21	48	25	III		E
295	37·5	100·5	27	5	23	10	11	42	III		E
			27	5	23	10	56	30	III		
			27	5	23	13	51	6	III		
			27	5	23	16	25	30	II		
			27	5	23	23	44	54	III		

No.	Lat. N.	Long. E.	Y.	M.	D	H	M	S	Int	Focal depth.	Region
295—*contd.*	37·5	100·5	27	5	24	9	3	30	III		
			27	5	24	9	15	20	III		
			27	5	24	16	1	24	III		
			27	6	23	23	42	15	III		
296	37·6	72·6	29	3	13	11	1	12	III		F
			30	7	31	0	7	30	II		
			33	6	19	22	34	9	II		
			34	9	1	9	2	51	II		
297	37·7	57·8	29	7	25	0	17	17	III		G
298	37·7	64·5	28	7	10	21	33	42	II		G
299	37·7	69·8	32	3	23	9	4	7	I		F
			33	7	20	4	19	33	I		
			34	6	19	1	4	42	II		
			34	7	5	7	30	40	III		
300	37·7	73·6	23	11	28	16	8	10	II		F
			26	12	19	11	1	30	II		
301	37·8	47·3	28	3	24	10	53	16	III		G
302	37·8	48·2	32	5	24	23	29	26	II		G
			32	5	24	23	31	51	II		
303	37·8	69·8	33	6	12	9	..	..	..		F
304	37·9	45·1	30	6	4	7	28	10	III		G
			30	10	25	23	34	25	III		
			34	2	22	8	7	20	IV		

No.	Lat. N °	Long E. °	Y.	M.	D.	H	M.	S	Int.	Focal depth	Region.
305	37·9	71·9	34	9	8	19	57	45	II		F
306	38·0	40·0	34	12	14	22	..	.	..		
307	38·0	42·0	26	10	9	19	16	0	II		G
			26	10	9	20	20	48	II		
			29	10	15	4	45	22	III		
			32	3	21	19	53	25	II		
			32	3	21	.	..	..	.		
308	38·0	43·0	24	7	25	21	39	24	II		G
309	38·0	43·8	30	4	16	21	25	42	II		G
310	38·0	48·5	17	6	2	0	28	12	II		G
311	38·0	56·8	29	5	1	15	37	22	IV		G
			29	5	1	22	42	45	II		
			29	5	13	13	27	3	III		
312	38·0	68·0	30	7	14	20	41	54	III		F
313	38·0	69·5	25	8	30	13	15	50	III		F
			27	4	28	0	49	42	II		
			33	12	9	7	52	16	III		
314	38·0	76·5	25	12	7	8	34	24	III		E
			30	3	1	5	35	9	II		
315	38·0	107·0	21	1	6	23	9	45	III		E
			21	1	7	9	42	25	III		
316	38·1	98·4	30	7	13	19	27	22	IV		E
			33	5	19	17	20	51	III		

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
317	38·2	70·9	33	3	28	4	55	13	I		F
318	38·3	72·8	31	12	16	19	33	20	II		F
319	38·3	86·8	33	9	25	18	51	29	IV		E
			33	9	25	..	..	..	..		
320	38·4	57·7	29	5	3	16	19	56	III		G
			29	5	4	6	31	12	III		
			29	5	13	6	32	22	III		
321	38·4	70·5	34	9	11	..	..	..	..		F
322	38·4	71·0	34	11	21	20	.	..	..		F
323	38·4	96·5	32	12	25	12	26	12	II		E
			34	3	11	19	9	55	III		
324	38·5	60·0	28	5	1	15	58	18	II		G
325	38·5	71·0	23	8	31	2	15	50	III		F
			26	7	6	16	28	5	III		
			27	4	18	15	1	45	III		
			34	9	8	6	45	5	III		
326	38·6	67·8	33	4	6	22	42	13	I		F
327	38·6	71·9	34	6	8	2	2	3	III		F
			34	9	1	6	50	40	II		
328	38·7	46·1	31	4	27	16	50	45	IV		G
			31	8	27	6	21	45	II		
			32	6	16	12	9	31	III		
			32	8	10	17	50	27	II		

No.	Lat. N °	Long. E. °	Y.	M.	D	H.	M	S.	Int.	Focal depth.	Region
329	38·7	70·5	29	3	6	16	59	23	I		F
			34	8	31	14	57	51	IV		
			34	9	1	12	31	21	II		
			34	9	3	2	49	5	II		
			34	9	5	10	19	50	II		
			34	9	11	14	7	0	II		
330	38·8	70·0	24	9	16	2	35	54	IV		F
			25	1	2	23	15	45	II		
			26	6	30	22	51	48	III		
			30	9	22	16	26	45	III		
331	33·8	71·2	33	4	30	13	6	51	I		F
			34	1	18	15	47	31	II		
			34	4	18	13	5	2	II		
			34	9	1	13	0	39	II		
			34	9	4	1	20	30	I		
			34	9	4	8	59	10	I		
			34	9	4	9	33	45	II		
			34	12	20	0	24	23	I		
332	39·0	47·5	24	2	19	6	59	45	IV		G
			31	7	5	17	57	22	III		
333	39·0	48·5	33	4	16	6	54	46	II		G
			34	6	8	2	2	3	II		
334	39·0	50·0	2	9	12	23	37	35	II		G

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
335	39·0	55·0	25	3	12	11	20	12	II		G
336	39·0	67·0	31	7	15	2	17	17	II		F
337	39·0	73·0	18	12	1	2	35	4	IV		F
			22	12	17	0	50	48	IV		
			25	2	1	19	33	36	II		
			26	8	26	10	29	42	III		
			27	1	20	8	46	45	III		
			32	7	17	11	37	14	II		
			32	8	16	21	53	48	II		
338	39·0	75·0	27	10	29	1	24	44	III		
			28	3	2	18	44	35	III		
			28	3	7	9	45	55	III		
			28	4	25	1	16	40	III		
			29	6	18	14	10	25	III		
339	39 0	78·0	27	10	31	23	29	45	III		E
340	39·0	81·5	27	5	2	22	4	55	III		E
			27	12	1	22	47	18	III		
341	39·0	95·0	17	9	4	16	42	16	IV		E
342	39·1	71·6	29	3	27	2	11	55	I		F
			29	3	27	2	36	8	II		
			29	3	27	3	37	18	II		
			30	1	7	17	27	42	II		
			34	9	3	10	19	22	II		

No	Lat. N °	Long. E. °	Y.	M.	D	H.	M.	S.	Int.	Focal depth.	Region.
343	39·1	72·4	34	2	20	20	6	32	II		F
			34	9	2	10	46	19	II		
344	39·2	73·6	30	8	9	22	41	9	II		F
345	39·2	96·4	32	12	25	2	4	31	IV		E
346	39·3	69·7	30	10	12	..	..	..	..		F
347	39·3	73·3	34	9	23	1	24	33	III		F
348	39·4	69·3	34	11	7	21	17	36	I		F
349	39·5	72·0	18	9	12	9	38	30	III		F
			23	12	20	15	13	20	III		
			26	5	2	10	0	32	IV		
			27	4	26	7	55	24	II		
			27	5	16	23	57	30	II		
			32	10	29	9	59	24	II		
			32	10	29	11	8	55	IV		
350	39·5	76·5	30	2	8	6	28	54	III		F
			30	4	10	14	24	10	III		
351	39·5	79·0	27	4	30	13	56	30	III		E
			28	3	18	..	..	..	..		
352	39·5	91·5	22	10	16	16	1	25	IV		E
			26	6	17	18	13	30	III		
353	39·7	53·3	28	11	6	13	42	25	II		G
354	39·8	71·3	33	4	2	13	0	33	I		F
355	39·8	74·3	31	4	26	0	13	57	I		F

No.	Lat. N. °	Long E. °	Y.	M.	D.	H.	M.	S.	Int	Focal depth.	Region.
356	39·9	49·3	34	11	2	22	6	11	II		G
357	40·0	60·0	19	7	14	14	22	0	III		G
			25	12	10	4	59	40	II		
			31	8	7	10	49	45	IV		
358	40·0	69·3	31	11	16	6	15	20	II		F
359	40·0	71·0	26	4	11	6	26	12	III		F
			31	7	23	4	45	56	I		
			33	9	9	19	34	18	II		
360	40·0	76·0	19	7	24	2	3	20	IV		F
			20	6	14	13	8	10	III		
			20	6	14	..	..	..	..		
			24	3	31	16	51	50	III		
			24	5	11	12	16	48	III		
			26	5	16	16	40	6	II		
361	40·0	78·0	25	8	5	20	11	33	III		F
			27	3	24	7	42	34	III		
			27	3	29	18	5	24	II		
362	40·0	110·0	18	4	10	2	3	44	IV		E
			27	5	27	2	54	40	III		
363	40·3	69·5	*23	12	28	22	24	42	IV	0·010	F
364	40·3	76·3	30	6	27	5	28	20	I		F
365	40·3	97·4	32	12	28	8	25	25	II		E
			33	1	17	15	59	58	II		

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M	S.	Int.	Focal depth.	Region.
366	40·5	71·8	33	4	13	4	54	54	I		F
367	40·5	82·5	23	6	21	12	25	0	III		E
368	40·5	90·5	17	10	17	1	24	50	III		E
369	40·5	96·0	33	7	11	7	46	30	III		E
370	40·7	72·8	33	4	19	15	31	37	II		F
			33	6	30	9	24	37	I		
371	40·7	77·7	31	4	2	1	34	46	I		F
372	40·9	75·0	32	4	20	20	5	49	II		F
373	41·0	72·5	27	8	12	10	22	33	IV		F
			27	8	12	16	16	34	III		
			27	8	12	17	45	54	II		
374	41·0	73·5	24	7	6	18	31	40	IV		F
			24	7	7	11	59	0	III		
			24	7	12	15	12	24	IV		
375	41·0	77·5	23	8	10	1	0	34	III		F
			23	8	10	2	17	20	III		
			27	9	15	8	30	50	II		
			34	7	28	2	6	32	III		
376	41·2	75·2	27	5	29	10	28	34	III		F
377	41·4	68·6	33	6	15	3	43	12	I		F
378	41·5	60·0	25	12	18	9	24	25	II		G
379	41·5	63·5	29	6	13	22	15	36	III		G
380	41·6	77·2	33	10	6	5	59	53	I		F

No.	Lat. N. °	Long. E. °	Y.	M.	D.	H.	M.	S.	Int.	Focal depth.	Region.
381	41·8	66·2	32	10	2	3	22	10	IV		G
382	41·9	75·9	34	9	27	22	51	19	II		F
383	42·0	72·5	28	3	30	1	1	18	III		F
384	42·0	74·0	28	8	23	3	53	25	III		F
385	42·0	79·5	32	12	24	4	17	15	II		F
			32	12	24	5	12	29	II		

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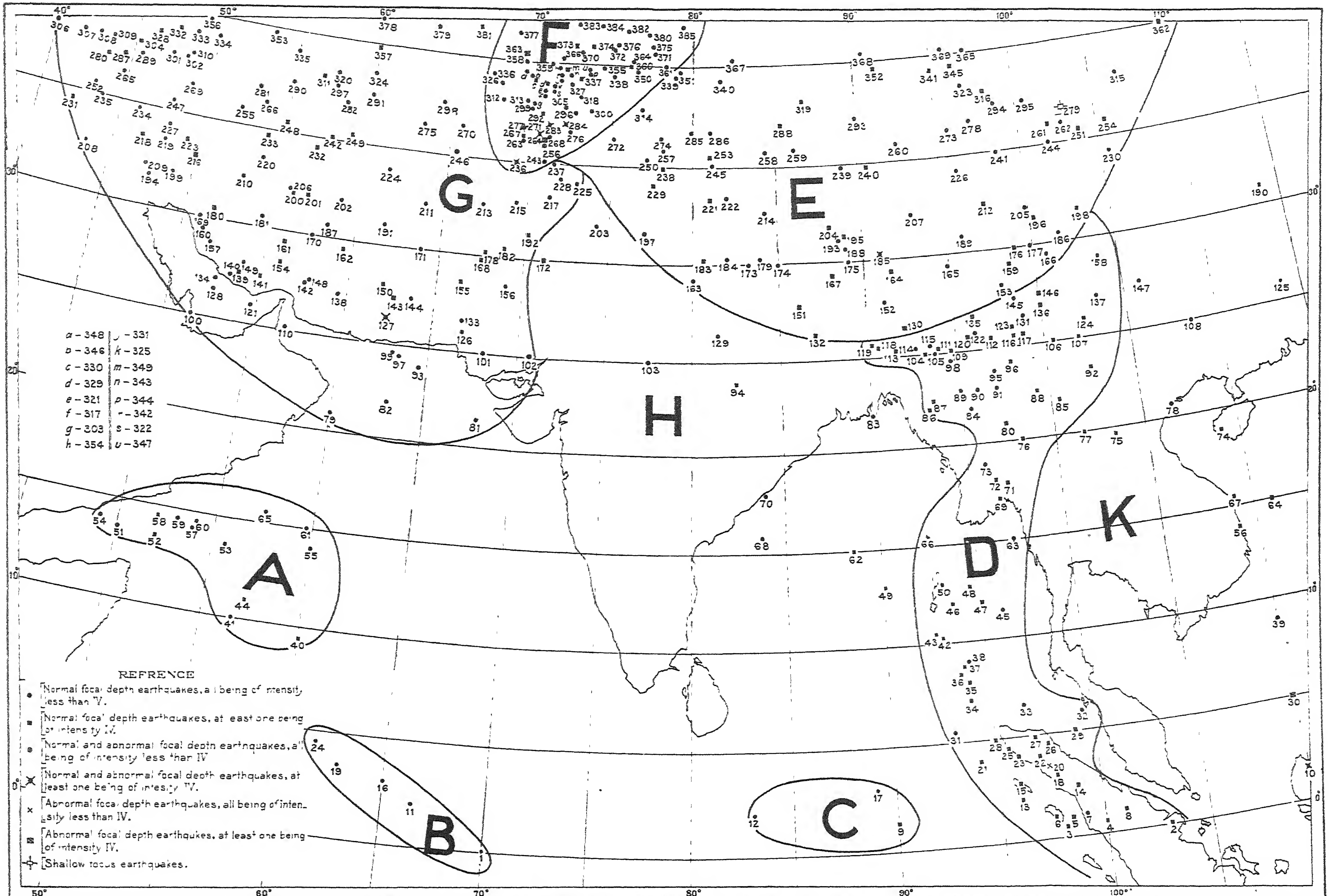

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BY

K. C. CHAKRAVORTTY

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AVIATION WEATHER RISKS AT DELHI

BY

K. C. CHAKRAVORTTY.

(*Received on 1st September 1947.*)

Abstract.—Delhi is an important station on the air-route. Occurrence of Weather phenomena adverse to aviation being of interest to pilots, the observational data collected by the Meteorological Office at the Willingdon Aerodrome, New Delhi, have been analysed to find out the average frequency and duration of occurrence of Different adverse weather elements (*viz.*, bad visibility, low-clouds, heavy rain, high winds, thunder-storms and dust-storms) for different months. An attempt has been made to explain the interesting features relating to the frequencies in different months. The diurnal variation of the adverse weather conditions in different months has also been discussed. The note concludes with two diagrams to show which months of the year and which hours of the days of these months are best and worst for aviation in regard to weather at Delhi.

INTRODUCTION.

Delhi is an important terminus of many internal air-routes and an important station on the Trans India Route to the Far East. Occurrence of weather phenomena which are adverse to aviation being of interest to pilots, particularly for determining the landing and taking off conditions, it is the purpose of this note to give an analysis of the observational data collected during the period 1940 to 1946 by the Meteorological Office at the Willingdon Aerodrome at New Delhi, which kept 24 hours current weather watch during these years.

2. Weather elements adverse to aviation.

As far as surface weather condition is concerned the following are considered to be the major aviation risks for a place like Delhi :—

(i) *Bad Visibility.*—When visibility falls below 1,100 yards.

(ii) *Low Cloud Base.*—When the height of base of the lowest cloud falls below 1,000 feet and at the same time the total amount of sky covered by the low clouds is more than $\frac{3}{4}$.

(iii) *Heavy Rain.*—Rain falling at the rate of 2″ per hour.

(iv) *Gale or high winds.*—When the wind force is 28 m.p.h. or more.

(v) *Thunderstorm* occurring at the station.

(vi) *Duststorm* occurring at the station.

These criteria have been used in the preparation of frequency tables, etc., presented in this note.

3. Frequency of occurrence of adverse weather elements and their diurnal and annual variation.

(i) *Bad visibility.*—(When Visibility falls below 1,100 yards.) The weather phenomena which commonly cause deterioration of visibility are fog or mist, precipitation, duststorm or dusthaze. The average number of days of bad visibility in each month at Delhi and the average duration of bad visibility on each such day are shown in *Table I*, the percentage frequency of occasions of bad visibility caused by different weather phenomena is shown in *Table II* and the frequency distribution of bad visibility at different hours of the day is given in *Table III*.

TABLE I.

Monthly frequency of bad visibility and its duration.

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Number of days of bad visibility.	3	1	1	1	5	5	1	*	*	0		1
Duration (in hours) of bad visibility on each day when it occurs.	3	3	2	1	3	3	1	1	1	*	1	3

* One day in 2 or more years.

TABLE II.

Percentage frequency of occasions of bad visibility caused by different weather phenomena.

	(Percentage frequency of occasions)											
	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Bad visibility due to—												
Fog	15	4	1	0	0	0	0	0	0	0	1	5
Duststorm or dusthaze .	0	0	2	7	27	28	2	1	2	0	0	0
Heavy precipitation or any other cause.	0	0	0	0	0	2	2	1	0	0	0	0

TABLE III.

Number of hours per 1,000 at which bad visibility occurred in different months

Month.	Hours																							
	0—1	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10	10—11	11—12	12—13	13—14	14—15	15—16	16—17	17—18	18—19	19—20	20—21	21—22	22—23	23—24
January	0	0	2	7	10	10	17	39	36	39	22	10	5	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	2	2	10	7	10	5	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	2	5	2	2	0	0	2	2	2	2	0	0	0	0	0	0	0	0
April	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	7	2	2	0	0	5
May	12	10	5	2	5	7	14	14	17	27	24	19	14	12	5	5	7	10	14	2	17	22	10	10
June	10	5	5	7	10	14	19	22	22	17	17	17	14	10	14	22	27	24	14	7	7	10	7	10
July	0	0	0	0	0	0	2	2	2	0	0	0	0	2	2	2	0	5	5	0	0	0	0	0
August	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	2	0	0	0	0	0
September	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	2	2	5	10	10	12	12	7	2	0	0	0	0	0	0	0	0	0	0	0

It will be seen that the frequency of bad visibility at Delhi is maximum in the hot months of May and June being about 5 days in a month and this is mainly due to the frequent occurrence of duststorms and thick dusthaze in these months. In May bad visibility is most frequent in forenoon and evening while in June it figures largely throughout the daylight hours. During January bad visibility is caused by fog and occurs on 3 days on the average mostly during the hours 0600 to 1100. Notwithstanding the low temperature reached at Delhi in the winter months, the frequency of fog even in the coldest month of January is quite low. This should be ascribed to the inland location of Delhi at an immense distance from the sea. The air in the cold season is usually very dry and only the most active western disturbances are able to draw enough moisture to produce foggy conditions. It is important that neither during May and June nor during January bad visibility persists for a long time, the average duration of bad visibility on a day of fog or dust being about 3 hours. During the months February to April and July to December bad visibility does not appear to be important at all for Delhi because its occurrence is very rare; the average monthly frequency being in no case more than one.

(ii) *Cloud height.—Table IV* below gives the average number of days of low clouds (7/10 or more) below 1,000 ft. above ground level month by month and the average duration of such low clouds on a day.

TABLE IV.

Monthly frequency of low cloud and its duration.

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Number of days of low cloud in a month.	2	*	0	0	0	*	3	3	1	*	0	1
Duration (in hours) of low cloud on each day of its occurrence.	5	4	..	..	..	4	5	4	5	3	..	3

* One day in 2 years or more.

The frequency of occurrence of low cloud at Delhi is not large in any month, the maximum frequency being only about 3 days per month during July and August, the months in which the activity of the south-west monsoon with its characteristic low clouds and precipitation is at its worst as far as Delhi area is concerned. In these months when the monsoon front passes over or very near Delhi, it gets large amounts of low clouds with very low base. During September when the south-west monsoon is at the state of withdrawal from this area the frequency of low cloud decreases to about 1 day on the average. Again under the influence of western disturbances in the months of December and January Delhi gets 1 or 2 days of low cloud on the average. The rest of the year (*viz.*, February to June, October and November) is almost free from this hazard. An interesting feature about low cloud condition is that once it has begun it does not die out quickly, the average duration being 4 to 5 hours on a day.

Table V gives frequency distribution of low cloud at different hours of the day in different months.

TABLE V.

Number of hours per 1,000 at which low clouds occurred in different months.

Month.	Hours.																							
	0—1	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10	10—11	11—12	12—13	13—14	14—15	15—16	16—17	17—18	18—19	19—20	20—21	21—22	22—23	23—24
January .	0	0	3	3	9	10	10	18	12	18	15	18	15	10	5	6	6	3	3	3	3	3	0	0
February .	0	0	0	0	0	0	0	0	3	3	3	6	6	6	6	3	0	0	0	0	0	0	0	0
March . .	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
April .	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May . .	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June . .	0	0	0	0	0	0	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July . .	3	3	6	12	15	21	27	21	27	30	30	21	21	15	15	15	12	6	6	3	3	3	3	3
August .	0	0	6	6	6	9	9	15	21	27	21	21	18	15	6	9	12	15	9	9	6	3	0	0
September .	0	0	6	6	6	6	10	10	10	12	12	9	9	9	9	6	3	3	2	2	2	0	0	0
October .	0	0	0	0	0	0	0	3	6	6	3	3	3	0	0	0	0	0	0	0	0	0	0	0
November .	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December .	0	0	0	0	3	3	3	3	3	9	12	6	3	0	0	0	0	0	0	0	0	0	0	0

A study of the above table brings out a marked diurnal variation of low cloud particularly during the monsoon months. The low cloud sets in generally in the early morning and the condition worsens with the advance of the day. After midday an improvement takes place gradually and the hours from sunset to midnight are almost free from low clouds. This can be explained by the fact that the surface temperature in the afternoon and evening is appreciably higher than that in the forenoon and early morning and the moisture content of the atmosphere remaining constant, the condensation level should rise with increase of surface temperature and as such the cloud height should also increase. If the low clouds are due to presence of fronts near Delhi as discussed before, the same will decrease with the advance of the day as convection will obliterate frontal structure in the lower levels.

(iii) *Heavy rain.*—The average number of days of heavy rain in different months of the year and the average duration of heavy rain per day are shown in *Table VI* below. The percentage distribution of heavy rain at different hours of the day is shown in *Table VII.*

TABLE VI.

Monthly frequency of heavy rain and its duration.

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Number of days of heavy rain in a month.	0	0	0	0	0	0	1	1	*	0	0	0
Duration (in hours) of heavy rain on each day of its occurrence.	.	.	.			.	1	1	1	.	.	..

* One day in 2 years.

TABLE VII.

Hourly percentage frequency of heavy rain in different months.

Month.	Hours.																							
	0—1	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10	10—11	11—12	12—13	13—14	14—15	15—16	16—17	17—18	18—19	19—20	20—21	21—22	22—23	23—24
July . .	0	0	0	0	0	3	3	3	3	3	0	0	3	3	3	3	0	0	0	0	0	0	0	0
August .	0	3	3	0	0	0	0	0	3	3	3	0	3	3	3	3	3	0	0	0	0	3	3	0
September .	0	0	0	0	0	3	3	3	0	0	0	0	0	3	3	3	0	4	3	3	3	3	0	3

N.B.—Hourly percentage frequency is *nil* at all hours during other months.

Heavy rain does not appear to be important at Delhi inasmuch as its occurrence is very rare and is limited only to the monsoon months July, August and September. The average frequency is less than a day in each of these months and the average duration of heavy rain is not more than an hour on such a day. There does not appear to be any marked diurnal variation in the occurrence of heavy rain.

(iv) *Gale or High Winds.—Table VIII* below gives the average number of days of gale or high winds month by month and the average number of hours during which the high winds persist on each such day.

TABLE VIII.

Monthly frequency of high winds or gales and their duration.

	January.	February.	March	April.	May.	June.	July.	August	September.	October.	November.	December.
Number of days of high winds or gales in a month.	0	1	2	1	5	5	2	*	*	1	0	*
Duration (in hours) of high winds or gales on each day of their occurrence.	.	5	5	6	5	6	4	2	3	3	..	3

* One day in 2 or more years.

The frequency of occurrence of gales or high winds is maximum during the hot months May and June, the average frequency being about 5 days in each of these months and the average duration being 5 or 6 hours per day. The frequency comes down to about 2 days in March and July with an average duration of high winds for 4 to 5 hours per day. During the remaining 8 months of the year gales or high winds are not at all important for Delhi because the hazard is either absent or occurs very rarely in these months.

The frequency distribution of directions of gales or high winds in different months of the year is given in *Table IX* below.

TABLE IX.

Wind.

Percentage frequency of directions of gales or high winds in different months.

Month.	Direction.							
	N.	NE.	E.	SE.	S.	SW.	W.	NW.
January . . .	0	0	0	0	0	0	0	0
February	0	0	0	0	1	1	1	2
March	0	0	0	1	0	1	2	5
April	1	0	1	0	0	0	2	2
May . . .	0	0	1	1	1	3	16	7
June	1	0	0	0	0	4	16	7
July . . .	0	0	0	2	2	3	5	2
August . .	1	0	1	0	0	0	1	0
September . . .	0	0	0	0	0	0	1	0
October	1	0	0	0	0	0	1	2
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	1	0

From a comparative study of the *Tables VIII and IX* it would appear that the majority of gales or high winds blow from a westerly or northwesterly direction particularly during those months of the year in which gales or high winds are considered to be important from the point of view of their frequency and duration.

Table X gives the frequency distribution of gales or high winds at different hours of the day in different months.

TABLE X.

Number of hours per 1000 at which gales or high winds occurred in different months.

Month.	Hours.																							
	0—1	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10	10—11	11—12	12—13	13—14	14—15	15—16	16—17	17—18	18—19	19—20	20—21	21—22	22—23	23—24
January .	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February .	0	0	0	0	0	0	0	0	0	0	2	2	3	5	5	6	7	7	7	2	2	0	0	0
March .	0	0	0	0	0	0	0	0	0	2	5	8	8	11	11	11	11	11	7	4	2	2	2	0
April .	2	2	2	2	0	0	0	0	0	2	3	3	5	5	5	5	6	7	7	3	0	0	0	0
May .	3	0	0	0	0	2	2	3	18	25	27	25	22	21	23	24	21	21	15	6	3	2	7	3
June .	0	2	2	2	2	2	3	11	29	34	34	31	31	26	26	25	25	20	11	2	2	3	4	3
July .	0	0	0	2	2	2	3	10	11	13	15	13	13	8	6	5	6	5	2	6	5	3	0	0
August .	0	0	0	0	0	0	0	0	1	2	2	2	2	1	1	2	1	0	0	0	0	0	0	0
September .	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	0	0	0	0	0	0	0	0	0
October .	2	2	2	2	2	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	0	1
November .	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December .	0	0	0	0	1	2	2	2	0	0	0	0	0	2	2	2	2	2	0	0	0	0	0	0

An interesting feature about the diurnal variation of gales or high winds is that in most of the months the frequency increases with the advance of the day, and decreases towards evening. During night hours the occurrence of this hazard is very rare. Thus the frequency more or less follows the diurnal variation of temperature. Quite naturally so, because barring the special circumstances the thermal effect of solar radiation is mainly responsible for surface wind structure.

(v) *Thunder.*—Thunderstorm is a major aviation risk because of its destructive violence ; large turbulent motion, severe wind gusts, poor visibility, exceptionally heavy showers of rain and often hail are its characteristic features.

The average number of thundery days in different months of the year at Delhi and the average duration of thundery condition on each such day are given in *Table XI* below.

TABLE XI.

Monthly frequency of thunder and its duration.

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Number of days of thunder in each month.	1	2	1	3	3	5	5	4	3	1	0	*
Duration (in hours) of thundery condition on each day of its occurrence.	3	2	2	2	2	2	$2\frac{1}{2}$	2	2	2	..	3

* One day in 2 years.

Delhi gets thunderstorms in almost all months of the year. The monthly frequency of occurrence is about 5 days in June and July, 3 or 4 days in April, May, August and September and 1 or 2 days in January, February, March and October. Taking the year as a whole 80 per cent. of the thundery days fall within the six months from April to September—pre-monsoon, monsoon and post-monsoon months. It is significant that the maximum frequency of thundery condition at Delhi occurs near about the time of onset of southwest monsoon. The few thunderstorms which occur during the cold season October to March are invariably associated with the cold fronts of western disturbances. Here also the moist southerly current of oceanic origin induced by the western depressions plays an important part in creating the thundery conditions. Although the frequency of thunderstorms is considerably less in winter than in summer, it is interesting that thundery condition once started on any particular day in the coldest months December or January persists for a slightly longer time than that in any other month the average persistance being about 3 hours in December and January and about 2 hours in the other months. The normal atmospheric condition being more stable in winter than in summer, the instability in a winter thunderstorm perhaps takes more time to be wiped out.

The frequency distribution of thunder at different hours of the day, month by month is shown in *Table XII*. It is observed that except during the months June and July thundery conditions have a tendency to predominate in the late afternoon and evening. This is because of the maximum instability of the atmosphere being established at these hours. In June and July besides afternoon and evening, the early morning hours (say 0200 to 0700 hours) also get a good number of thunderstorms. These thunderstorms in the early mornings are evidently not heat thunderstorms. It is probable that the Katabatic flow or the flow of air from nearby thunderstorms or presence of nearby fronts which will be well marked at these hours due to absence of insolation or radiative cooling of cloud tops is responsible for relatively greater frequency in the early morning hours.

Table XII.

Number of hours per 1000 at which thunder occurred in different months.

Month.	Hours.																							
	0—1	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10	10—11	11—12	12—13	13—14	14—15	15—16	16—17	17—18	18—19	19—20	20—21	21—22	22—23	23—24
January .	0	0	0	2	3	3	3	2	2	2	0	0	0	0	0	2	0	0	2	3	3	0	0	0
February .	4	5	5	7	7	5	5	0	0	0	0	0	2	2	2	2	3	7	7	7	8	9	7	4
March .	0	0	0	0	0	3	3	2	0	0	0	0	0	0	0	2	2	5	8	7	7	5	5	2
April .	2	2	2	3	5	5	5	5	3	3	0	0	0	2	3	3	12	9	9	8	6	5	4	2
May .	3	3	2	3	4	4	4	5	3	3	0	0	2	3	7	12	8	5	3	2	2	3	5	8
June .	5	6	9	14	14	15	12	9	7	3	3	7	7	6	5	7	5	7	4	4	5	5	5	5
July .	3	5	11	15	11	11	7	5	1	3	3	5	9	8	9	15	15	15	9	5	5	7	7	4
August .	2	3	2	3	3	3	2	2	2	3	5	6	5	8	13	13	16	15	8	8	7	5	3	2
September .	3	2	2	2	3	2	3	3	3	2	2	3	5	7	8	8	3	0	5	5	2	2	0	2
October .	2	2	2	2	2	0	0	0	0	0	0	0	2	2	2	3	5	3	2	2	3	5	2	2
November .	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December .	0	0	0	0	2	2	3	3	0	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0

(vi) *Duststorm.*—The conditions which give rise to duststorms are practically same as those for thunderstorms except that the extreme dryness of the atmosphere in case of duststorms rules out any condensation, the effect of the cumulonimbus cloud being confined to large air currents which raise dust from the ground.

The average number of days of duststorms at Delhi in different months of the year and the average duration of duststorm per day are shown in *Table XIII* and the frequency distribution of duststorms at different hours of the day is given in *Table XIV*.

Table XIII.

Monthly frequency of duststorms and their duration.

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Number of days of duststorm in each month.	0	0	*	1	3	4	*	*	*	0	0	0
Duration (in hours) of duststorms on each day of its occurrence.	..	..	1	1	2	2	1	½	½	..	..	..

* One day in 2 or more years.

TABLE XIV.

Hourly percentage frequency of duststorms in different months.

Month.	Hours.																							
	0—1	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10	10—11	11—12	12—13	13—14	14—15	15—16	16—17	17—18	18—19	19—20	20—21	21—22	22—23	23—24
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March .	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
April .	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	1	1	0	0	1
May .	2	2	1	1	0	0	0	0	1	2	2	3	1	1	1	1	1	2	2	2	3	4	2	2
June .	2	1	1	1	0	0	0	1	1	1	1	1	1	1	3	5	7	6	1	3	3	3	1	1
July .	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
August .	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Although duststorm is considered to be one of the major aviation hazards an aviator need not worry much about it as far as Delhi is concerned. The frequency of duststorms at Delhi is not at all large and its occurrence is limited practically to the three months April to June. On the average, duststorms occur on 3 to 4 days per month in May and June and on one day in April; the average duration per day is about 2 hours in May and June and 1 hour in April. No marked diurnal variation in the occurrence of this phenomenon is noticeable except for the fact that duststorms like thunderstorms have a tendency to occur in the afternoon and evening during hot months. Here also the maximum instability of the atmosphere in the afternoons and evenings during hot months is mainly responsible for this feature.

4. Conclusion.

From a practical point of view, so that he may take the necessary precautions, an aviator may be interested to know which months of the year and which hours of the days in those months are best and worst for aviation in regard to weather at Delhi. In order to meet this point, the frequency of days of adverse weather at Delhi (irrespective of the type of weather) in different months, the average duration of adverse weather on each such day and the hourly frequency of the sum total occasions of adverse weather in different months have been found out and shown in *Tables XV and XVI*. From this point of view, the unfavourable months for Delhi are May, June, July and August, the summer and monsoon months. On an average 10 days in May, 12 days in June, 10 days in July and 6 days in August are associated with adverse weather, the unfavourable condition persisting, on the average, 5 to 6 hours in May and June and 3 to 4 hours in July and August. The rest of the year, and the months of October, November and December in particular, with their cloudless skies, brilliant sunshines and still air, is practically free of unfavourable conditions, excluding of course the occasional occurrences which do not come out in the averages.

From a study of the diurnal variation of the adverse weather elements as shown in *Table XVI* it would appear that the frequency of occurrence of the adverse weather elements in the 4 most disturbed months May to August is appreciably greater during the day-light hours than at night. In December and January adverse elements are confined to the mornings while in March and April they occur mostly in the late afternoons and evenings. It is significant that in all months, except May and June, the best aviation weather in the 24 hours occurs during the middle part of the night, say 2100 hours to 0200 hours. The *Figs. I and II* directly show the hours in different months at which the weather elements adverse to aviation are "most frequent" and "least frequent".

TABLE XV.

Monthly frequency of days of adverse weather and the average duration of adverse weather on each day of its occurrence.

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Number of days of adverse weather (any type) in a month.	4	4	3	4	10	12	10	6	4	2	*	1
Duration (in hours) of adverse weather on each day of its occurrence.	5	3	3	3	5	6	4	3	3	2	1	3

* One day in 7 years.

TABLE XVI.

Number of hours per 1000 at which any type of adverse weather occurred in different months.

Month.	Hours.																							
	0—1	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	9—10	10—11	11—12	12—13	13—14	14—15	15—16	16—17	17—18	18—19	19—20	20—21	21—22	22—23	23—24
January .	0	0	1	2	4	5	6	11	10	10	7	5	3	1	1	1	1	1	1	1	1	1	0	0
February .	1	1	1	2	2	3	3	2	1	1	1	1	2	3	2	4	4	4	4	3	3	4	2	1
March . .	0	0	0	0	0	1	1	1	1	1	1	2	3	4	5	5	4	5	6	3	2	2	2	1
April . .	2	1	2	1	1	1	1	1	1	1	1	1	1	2	2	2	7	6	8	5	3	0	1	2
May . .	6	4	2	2	3	4	4	5	10	15	16	13	11	10	9	12	11	10	10	4	8	9	7	7
June . .	5	5	6	7	8	9	9	12	17	16	16	16	16	12	14	16	18	17	9	5	5	7	6	5
July . .	1	2	5	7	7	8	9	9	9	10	11	8	10	7	8	9	8	9	6	4	3	3	2	2
August .	1	1	1	2	2	2	2	2	4	5	4	6	5	5	5	7	7	7	5	3	2	1	1	1
September .	1	1	1	1	2	2	4	3	2	2	2	2	3	4	5	4	1	1	4	3	1	1	0	0
October .	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1
November .	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
December .	0	0	0	0	1	2	2	3	2	3	3	1	0	0	0	0	1	1	1	1	0	0	0	0

I should express my grateful thanks to Mr. J. M. Sil, Director, Regional Meteorological Centre, New Delhi, for the facilities he so kindly extended to me in the preparation of this note and for his valuable suggestions.

MGIPC—M—XI-1-68—25-2-49—500.

Sc. Note No 130.

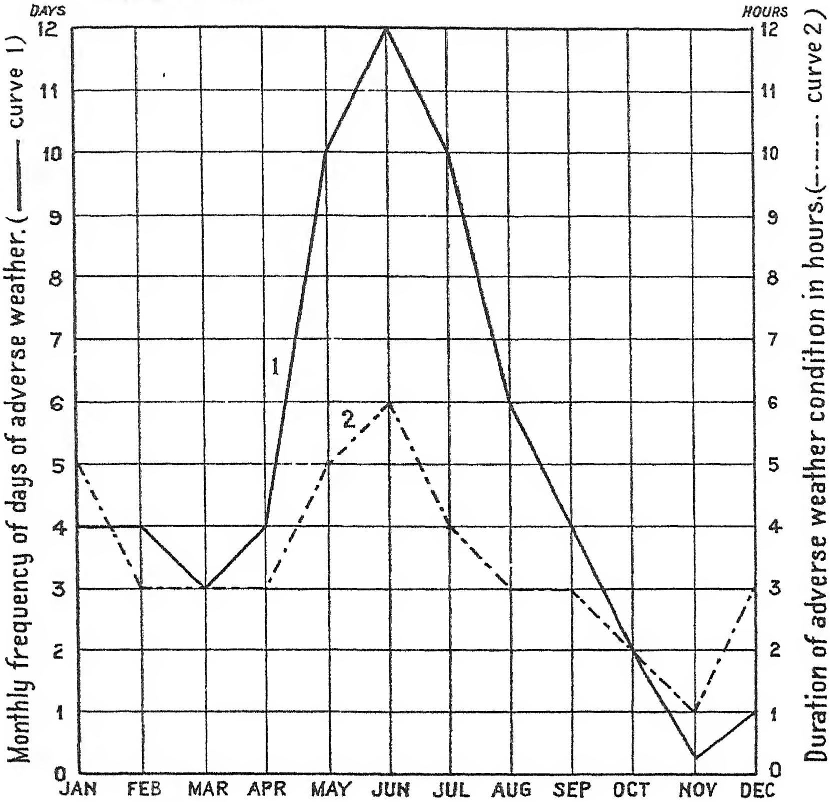
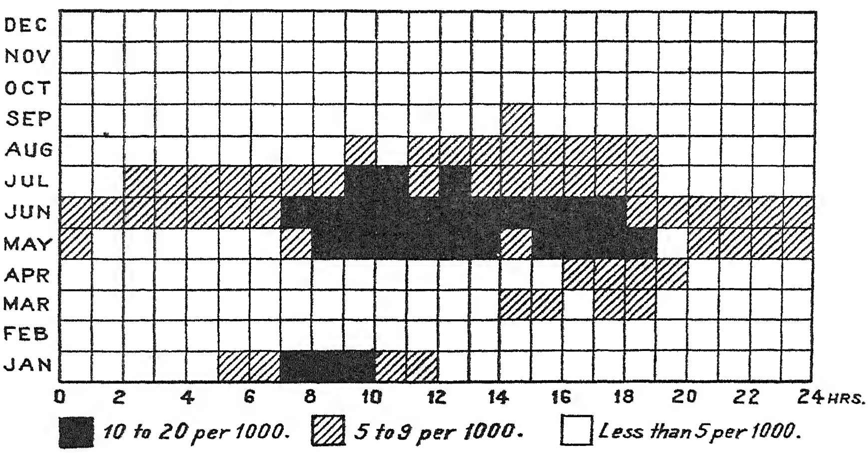


FIG. 1.



FREQUENCY OF OCCURRENCE OF ADVERSE WEATHER.

FIG. 2.